Fixed Location Hydroacoustic Estimation of Fish Migration in the Riverine Environment: An Operational Manual

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FIXED LOCATION HYDROACOUSTIC ESTIMATION OF FISH MIGRATION IN THE RIVERINE ENVIRONMENT: AN OPERATIONAL MANUAL

by

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ABSTRACT

Enzenhofer, H.J. and G. Cronkite. 2000. Fixed location hydroacoustic estimation of fish migration in the riverine environment: An operational manual. Can. Tech. Rep. Fish. Aquat. Sci. 2312: 46p.

The aim of this manual is to assist those developing a fixed-location hydroacoustic site for estimating fish passage in a river. We have been using split-beam hydroacoustics combined with automated tracking since 1993 at the Qualark Creek site on the Fraser River near Yale, British Columbia, Canada. Riverine sampling conditions are acoustically challenging, requiring specialised in-river equipment, proper selection of acoustic sampling techniques, development of software packages to handle data and the ability to recognise potential malfunctions of the acoustic equipment. We describe how to select a site for deployment of the acoustic gear and the specialised in-river equipment, modifications to a site to make it favourable for acoustic sampling as well as costs for performing the modifications. We describe the design and use of in-river equipment that aids the operation of a fixed-location hydroacoustic system. Several types of fish deflection weirs, designed to move fish away from the shore so that they can be counted, are described for use in rivers with varying morphological conditions. Other equipment is described which allows the accurate aiming of the acoustic beam, maintenance of a constant beam configuration during equipment moves and the performance of beam geometry experiments. Beam geometry experiments reveal the detection characteristics of the acoustic system and allow the selection of an appropriate transducer as well as the acoustic parameters for data collection. Recognition of a malfunction of the acoustic equipment is critical to accurately estimating fish passage. We describe how to identify the nature of a problem and how to systematically pinpoint the specific piece of equipment that produced the failure. We also describe data editors that have been developed by our group to view and edit large quantities of acoustic data and our method for developing and presenting the daily data to the fisheries managers.

RÉSUMÉ

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Le présent manuel est destiné aux personnes oeuvrant à la mise au point de postes statiques de dénombrement des poissons se déplaçant dans les eaux d'une rivière. À cet égard, on utilise depuis 1993, au poste de Qualark Creek, sur le fleuve Fraser, près de Yale, en Colombie-Britannique (Canada), un système hydroacoustique à faisceau partagé combiné à un système de repérage automatisé. Les conditions d'échantillonnage fluvial sont passablement difficiles sur le plan de l'acoustique et nécessitent le recours à du matériel spécialisé de détection en eau vive et à des méthodes appropriées de prélèvement acoustique, de même que la mise au point de progiciels de manipulation de données ainsi qu'une aptitude à reconnaître les défectuosités du matériel utilisé. Le présent manuel porte sur différents aspects, notamment la façon de choisir un site pour l'installation du matériel acoustique et du matériel spécialisé destiné à l'exécution de travaux en eau vive, les modifications devant être apportées à un site pour le préparer en vue de travaux d'échantillonnage acoustique, y compris les coûts associés à de telles modifications, ainsi que le matériel destiné à faciliter l'exploitation d'un système statique de repérage acoustique et le mode d'utilisation de ce matériel. On y trouve également une description de divers types de déversoirs destinés à orienter les poissons loin du rivage pour faciliter leur dénombrement, et conçus pour être utilisés dans des cours d'eau présentant une morphologie irrégulière, de dispositifs et d'appareils destinés à assurer l'orientation précise du faisceau de sondage acoustique ou encore le maintien de la configuration du faisceau lors de déplacements du matériel, ainsi que différentes études sur la géométrie du faisceau. Ces dernières mettent en évidence les caractéristiques de détection du système acoustique en plus de faciliter le choix d'un transducteur approprié ainsi que des paramètres acoustiques de collecte des données. L'aptitude à déceler une défectuosité du matériel acoustique est essentielle au maintien de la précision de dénombrement de ce dernier. Le présent manuel fait état d'une méthode de recherche de pannes et de repérage systématique des pièces défectueuses. Il décrit également les différents programmes de mise en forme des données, élaborés par des membres de notre groupe, qui permettent de visualiser et de manipuler un grand nombre de données acoustiques, ainsi que la méthode de production de données quotidiennes et de présentation de ces dernières aux gestionnaires de pêcheries.

1.0 INTRODUCTION

Acoustic systems have been used to monitor abundance of returning adult anadromous salmonids (*Onchorhynchus* spp.) since the 1960's in North America (Gaudet 1990, Johnston and Stieg 1995). More recent advances in hydroacoustic technology resulted in the development of the split-beam system capable of measuring the three-dimensional position of a target in the acoustic beam. When the split-beam system is coupled with an automated tracking algorithm, the result can produce real-time estimates of fish passage (Ehrenberg and Torkelson 1996). The ability to provide timely and accurate estimates of fish passage in rivers is essential to ensure that escapement goals are achieved.

Working in rivers is challenging due to the variable conditions encountered while attempting to deploy equipment. Heavy current flow, fluctuating river levels, debris, and low signal-to-noise ratio are all factors which require specialised equipment and sampling techniques to overcome their impacts.

Manuals produced by the manufacturers of electronic equipment are specific to the instruments themselves and do not cover the overall methodology for producing an acoustic estimate. We present this manual as an aid to those who will be attempting to develop a hydroacoustic-monitoring site. The manual addresses all aspects of the site operation from the initial site selection to the production of the 24hr-passage estimate. We do not cover the theory of hydroacoustics in depth, since a basic knowledge of acoustics is assumed for anyone attempting to develop such a program.

Methods are described to:

1. Choose an appropriate site that will meet the criteria required to apply acoustic technology. Modifications to the riverbed that can make a poor site favourable are included.

2. Select acoustic sampling equipment and system parameters that will optimise the detection of migrating fish.

3. Apply specialised in-river accessory equipment that aids the acoustic measurements.

4. Standardise the aiming of a transducer to ensure adequate coverage of the water column, especially in the areas where fish passage occurs.

5. Develop a methodology using the data collected to produce a daily count of fish passing the site.

The equipment and techniques were all designed and perfected at the Qualark Creek facility on the Fraser River in British Columbia, Canada from the period between July 1993 to August 1998. The Fraser River, one of the world's largest producers of sockeye salmon (*Onchorhynchus* nerka) has discharge rates from a low of 500 m^3s^{-1} to highs of 12,000 m^3s^{-1}. It has heavy harvesting pressure and at times difficult environmental conditions for migrating fish.

We include some of the costs in Canadian dollars to perform bank modifications and to purchase specialised in-river equipment that will aid the acoustic monitoring of fish passage. The remoteness of a site will increase some costs. The overall cost of running a site with road access to one bank will be presented.

We felt the necessity to present the information in this report to pass on what we have learned through trial and error over the last six years. We have spent much time and effort in developing a riverine acoustic site and testing the methodology to produce what we feel is an accurate method of enumerating millions of migrating salmon in the Fraser River. It is our hope that others may use this information to decrease the development time for their projects in other rivers. It is information like this, at the operational level, that would have been very useful for us in the past, but it did not exist. This report also acts as a record of what we have accomplished over these years, now that our work at Qualark Creek has been terminated.

2.0 CHOOSING A SITE

Selection of a hydroacoustic site should meet the criteria that fulfil the needs of the fisheries manager as well as those required to perform acoustic work. First, the location should provide the fisheries managers with passage data that adequately represent the number of fish migrating up the river. Generally this means the site needs to be located in the lower reach of the river where all fish would pass the hydroacoustic system and not branch off into tributary streams or rivers below the site. An aerial survey of the river by helicopter is helpful in selecting potential sites or rejecting others. Sites can quickly be eliminated if they exhibit characteristics such as white-water, cliffs on one bank, or have more than one channel. Sites can be marked for further investigation if they meet some general requirements during the initial flyover such as:

1. The river should have a straight single channel, not meandering, with laminar water flow. Laminar flow will produce less acoustic background noise than turbulent flow, resulting in a greater signal-to-noise ratio and hence, a greater ability to detect targets. River stretches that exhibit back-eddies and pools may cause milling behaviour that can result in fish being repeatedly counted.

2. The river bottom profile should be planar, rather than shelved or scalloped. A shelved bank creates zones of the riverbed that are inaccessible to the acoustic beam.

3. The bottom substrate size should be moderate and free of large boulders. Boulders can interfere with the path of the acoustic beam or create turbulent flow.

4. Activity on the river should be minimal because such things as propeller wash entrains air bubbles, which create background noise. Activities that may alter fish migration behaviour should be avoided as this may affect the acoustic count.

5. Fish should be actively migrating past the site and not holding or milling. Fish that tend to remain in the sampling area may be counted several times which results in overestimates.

It is advisable to survey potential sites to determine the bank and bottom profile during the period when the water level is at the lowest point. This will help to determine the type of bank modifications required which will optimise the acoustic detection of fish when water levels are higher. It is also advisable to measure background noise level with the acoustic system that will be used to monitor fish passage. For example, if the measured background noise was higher than the expected return signal of a calibration sphere used to test the system, then the choice of site is poor. Often the noise may be created by an upstream obstruction creating turbulent water flow. It may be possible to reduce the effect of some obstructions by removing them or by modifying the riverbank.

3.0 MODIFICATIONS TO THE RIVER BANK

The acoustic site should have plane bank profiles for the entire area in which fish passage occurs and for the entire period that fish migration takes place. This allows the acoustic beam to be positioned close to the river bottom in order to detect moving fish. A potential site, which meets most of the site selection criteria but possesses some irregularity in its bottom composition or profile, may be a candidate for bank modification.

For example, the Qualark Creek site on the Fraser River met all the site selection criteria except for some unevenness in both bank profiles and the existence of large boulders up to 2 m in diameter. This was not discovered until water levels began to recede during the first year of operation. During a period when the river level was at its lowest, the large boulders were blasted to produce hand-manageable sizes. A hand operated gas powered rock drill with 2.54 cm diameter drill bits was used. The smaller sized rock was either placed downstream from the acoustic site or arranged to conform to an even bottom slope. Since it was possible to bring excavating machinery to one bank, we could create an ideal site that conformed to the natural bank slope of 20°. The surface layer, consisting of 30-50 cm diameter river rock, was removed and replaced with 5 cm of crushed rock for the entire area to be

acoustically monitored. Partially filled and flattened sandbags were placed on top of the crush to create a ramp, 9 m wide by 35 m long, which ran down the river bank, perpendicular to the shoreline. This length of ramp was required to cover water levels that existed between spring high water and early fall low water periods. The sandbag ramp is less reflective of sound than rock; thus allowing the acoustic beam to be aimed closer to the bottom. Typical to many rivers, the opposite bank did not have road access and required all the work to be done by hand. This does not make bank modifications impossible. It does increase costs and labour.

Shown in Table 1 are some costs and the time taken to perform the modifications at the Qualark Creek site. Although these figures are specific to this site, they give a general idea of what is required to perform similar work on other rivers. It should be noted that there was road access on one riverbank and boat access only to the opposite bank.

Table 1: Costs for bank modifications performed at Qualark Creek.

Item	People	Days	Cost
Rock drilling & Blasting	3	3	$3,000
Preparation of sandbag ramp to bank with road access	5	6	$17,000
Preparation of sandbag ramp to bank with boat access	6	10	$27,000

4.0 IN-RIVER ACCESSORY EQUIPMENT

In rivers with moderate to high flow rates, fish migrating upstream tend to be bank and bottom oriented because flow rates are lower in these regions and it is easier for fish to navigate. To monitor their passage, the hydroacoustic system in most cases is deployed in a fixed-location with a shore-based transducer aimed perpendicular to the water flow. Fish migrating close to shore often must be forced offshore to pass through the far field of the acoustic beam where the probability of tracking is greater.

Any deployment of equipment is difficult in rivers having high flow rates or water levels that fluctuate. To make acoustic measurements in these rivers requires the use of specialised in-river equipment designed to withstand the forces of the river (Enzenhofer and Cronkite 1998). We designed, constructed and utilised such equipment (Fig. 1) at the Qualark Creek facility. This equipment consisted of:

1. A fish deflection weir which forces fish to move offshore and pass through the far field of the acoustic beam where the probability of detection is greater.

2. A transducer-to-weir bracket, which holds the transducer assembly, and allows a repeatable beam configuration during equipment moves.

3. A reference target frame, with an attached acoustic target, that can be used to aim the acoustic beam, take routine system calibration measurements and perform *in situ* beam geometry experiments.

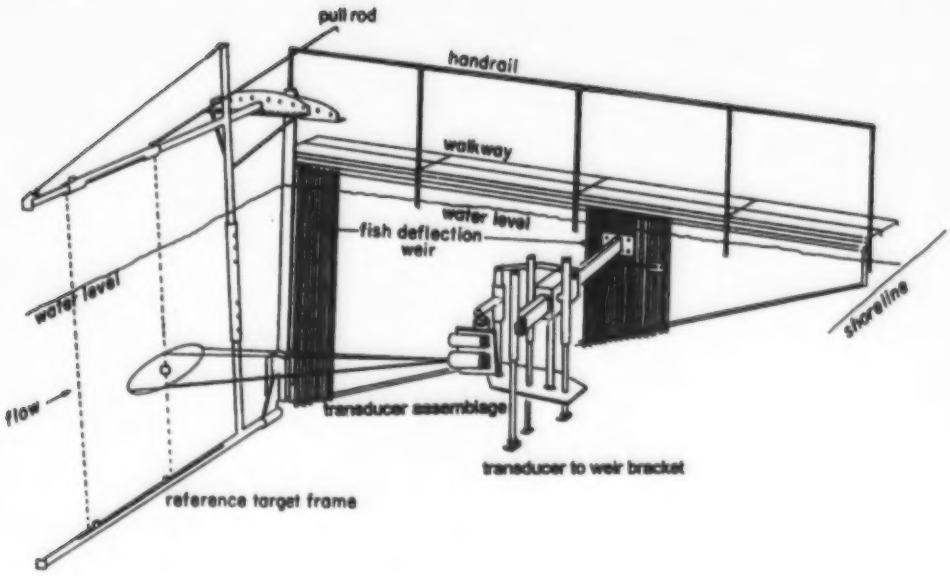

Fig. 1 Three-dimensional view of the in-river accessory equipment that includes the reference target frame, the transducer-to-weir bracket and the fish deflection weir equipped with a walkway and handrail.

Since gross morphological conditions vary between rivers, a particular equipment design that works at one site may require modification to be used at another site. We present possible modifications for each piece of the in-river accessory equipment in the description. Table 2 lists approximate costs for the equipment in Canadian funds.

Table 2: Approximate cost for in-river accessory equipment and accompanying equipment developed at the Qualark Creek facility on the Fraser River, British Columbia, Canada.

Equipment	Description	Cost
Fish deflection weir (automated)		
-track system	Double track (1 section = 3.7 m (12') length) (8) – 3.7 m sections used	$ 6,400
-track pegs		$ 750
-winch mount platform	Includes 12v battery	$ 1,500
-winch and 10 mm galvanised cable	Warn model 8000x (3600 kg)	$ 1,200
-fence panel with walkway	Includes handrail, bracing and track carriage system	$ 8,000
-optional alternate cable and pulley system	60 meters of 10 mm galvanised cable & 10 cm pulley	$ 200
Stationary walkway and fence	(5) – 3.7 m (12') sections	$11,000
Stationary weir panel with anchor pins	6 m panel	$ 3,000
Adjustable reference target frame	Aluminium with 3 main support members	$ 3,000
Access to fish deflection weir end	-manual winch, 6.4 mm cable (1/4") and mounting plate	$ 1,800
Transducer-to-weir-bracket		$ 4,500
Tri-pod	Includes optional 25 kg steel plate	$ 1,000
Transducer-aiming unit	-transducer mounting plate -gooseneck holder -rotator to gooseneck mounting plate	$ 2.000
Dual-axis rotator	Includes rotator controller, cable and software	$ 9,000
Underwater instrumentation package	Includes cable and software	$ 5,000
Adjustable cable reel	Fits spools up to 1 m diameter	$ 400

4.1 FISH DEFLECTION WEIR

The fish deflection weir is a free-standing structure supported by a brace system connected to a double track that runs perpendicular to the river flow. The deflection weir forces fish offshore to pass through the far field of an acoustic beam whose transducer has been mounted on the upstream side and shore end of the weir. The plan view (Fig. 2) illustrates the automated fish deflection weir and track system.

The weir is 6 m long, trapezoidal in shape to conform to the riverbank, and prevents fish from migrating under or through it. A walkway with handrails runs along the top of the weir to provide foot access along its length. Having foot access allowed us to operate equipment such as the reference target frame, which was attached to the weir. The weir was moved up and down the track with an electric winch mounted on a platform that was attached to the top of the tracks. A complete description and the construction details can be found in Enzenhofer and Olsen (1996).

The walkway also provided a working platform for doing acoustic experiments designed to measure the detection characteristics of the acoustic system. Since the facility was used for the development of acoustic equipment and the advancement of acoustic assessment techniques, having the ability to work in the far field of the acoustic beam was paramount. We accomplished this by adding a working platform to the fish deflection weir and a winch system to deploy the reference target frame (Fig. 3).

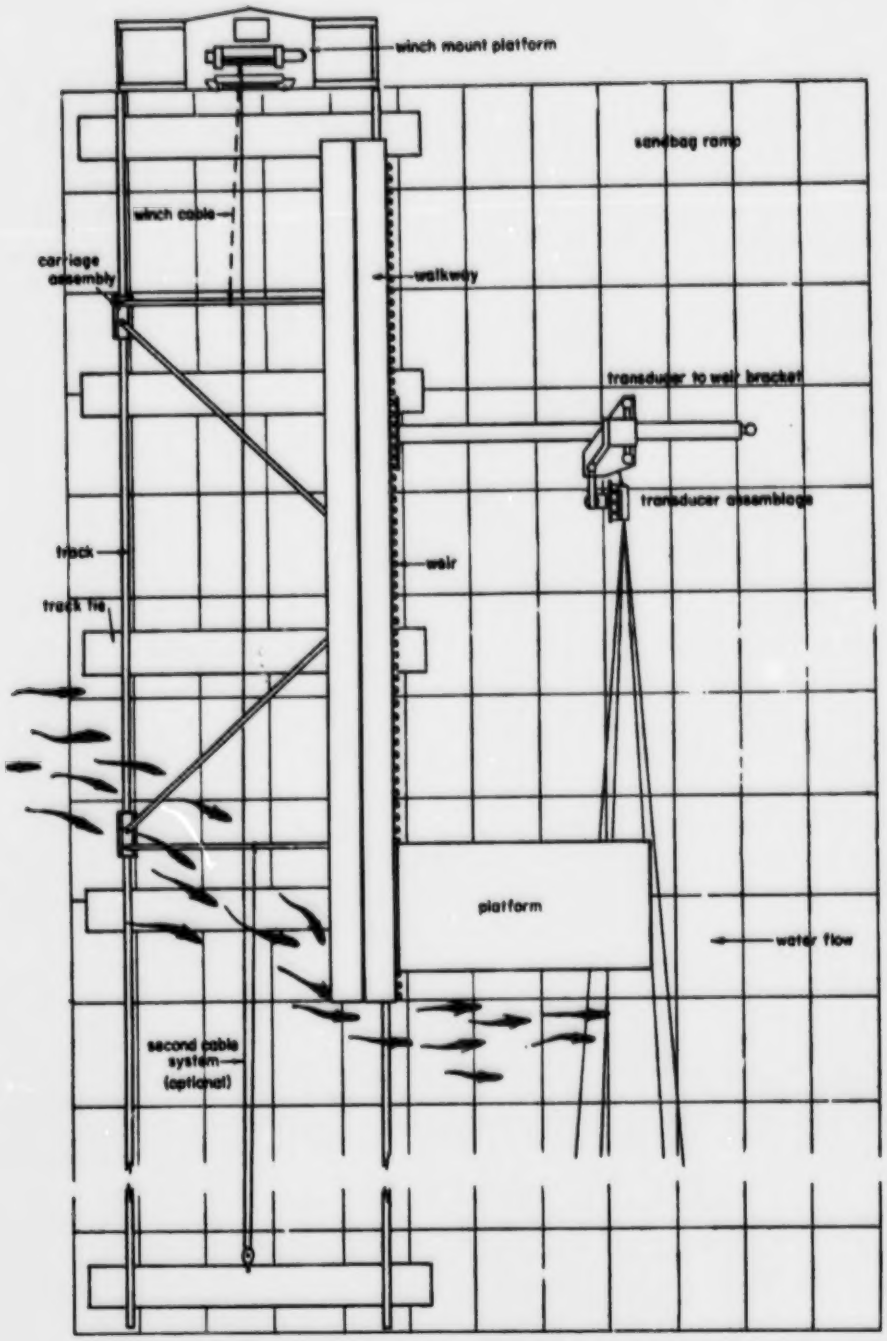

Fig. 2. Plan view of the automated fish deflection weir and track system operated from a shore based winch. Also shown are the working platform, the transducer-to-weir bracket and an optional second cable system for operation in rivers having a low gradient substrate. All equipment has been installed onto a sandbag ramp.

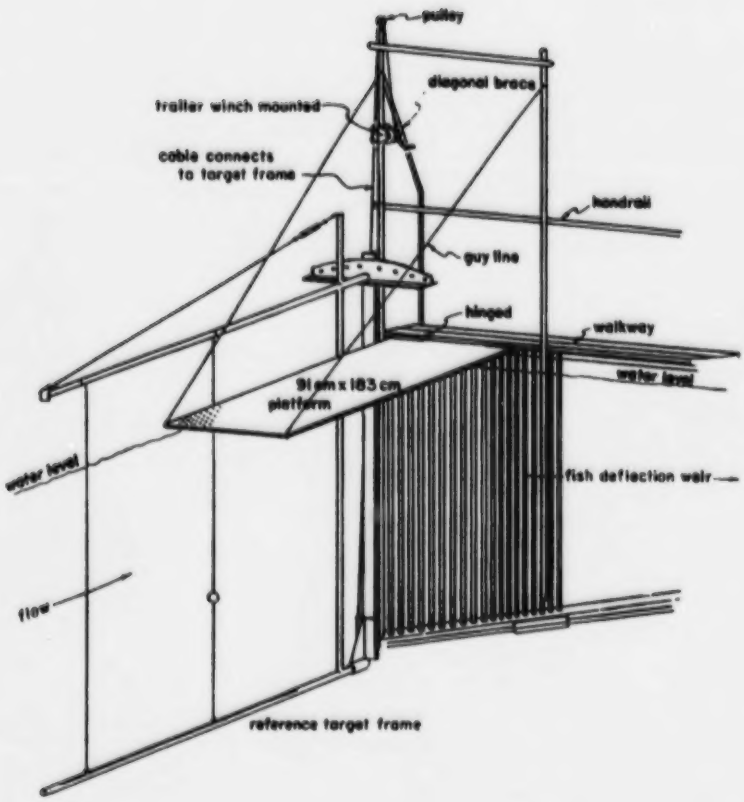

Fig. 3. Three-dimensional view of the fish deflection weir, the working platform and the winch operated reference target frame.

4.1.1 Modifications to the fish deflection weir

The automated track and weir system at Qualark Creek relied on the weight of the weir and the 20° slope of the bank to automatically roll out the weir assembly. The weir was lowered into the river simply by reeling out the winch cable. Rivers having a more gradual slope would require a second cable system that attaches to the winch to pull the weir out into the river. This can be done by running a 10 mm galvanised cable from the deep end of the weir down through a pulley mounted in the centre of the last track section and back up to the winch. If equipment was to be moved frequently, the addition of a second winch would eliminate the need to disconnect cables when reeling the weir in or out. The second cable system is shown in Fig. 2 and is labelled *second cable system (optional)*. Not all of the track sections are shown in this figure. A brake in the track section followed by the final track tie with attached pulley denotes this.

If river levels remain fairly constant throughout the migration period, a stationary type fence could be constructed instead of the automated track and weir system. We have designed two types of stationary fences for our work in the Fraser River system. The type used in the Thompson River, a clear water tributary of the Fraser River, is described in Enzenhofer et al. (1998). This fence consisted of 3.7 m sections of walkway (SHUR GRIP galvanised steel grating), supported by a brace system constructed of 3.5 cm schedule-40 galvanised pipe (Fig. 4). The support braces were anchored to the river bottom with three steel pins. Commercially available KEE KLAMP slip-on pipefitting was used to connect all the pipe

sections to allow for adjustments during the assembly phase. The fish deflection fence attaches to the upstream side of the walkway and consists of 1.9 cm galvanised conduit pipe placed on 5.7 cm centres. Each length of conduit pipe was removable from the bracket holder in order to clean the fence. The fence was operated in water up to 3 m in depth, but could be easily modified for operation in deeper water simply by increasing the length of the fence conduit pipe and raising the height of the walkway by raising the deck support braces.

The second type of stationary fish deflection weir consisted of a single aluminium panel, trapezoidal in shape to conform to the river bottom, and held upright by two steel anchor pins (Fig. 5). The anchor pins run diagonally to the river bottom on the downstream side of the weir panel through two support brackets bolted on top and at either end of the weir panel. Each support bracket can hold a 2.54 cm diameter pin in either direction depending on which side of the river the equipment is to be deployed. The height and length of the weir panel as well as the length of the anchor pins is dependent on the water depth. This weir was deployed with a landing craft-style vessel that had a hand winch crane on each gunnel. This style of weir works best in areas with sand or silt substrates and lower current velocities.

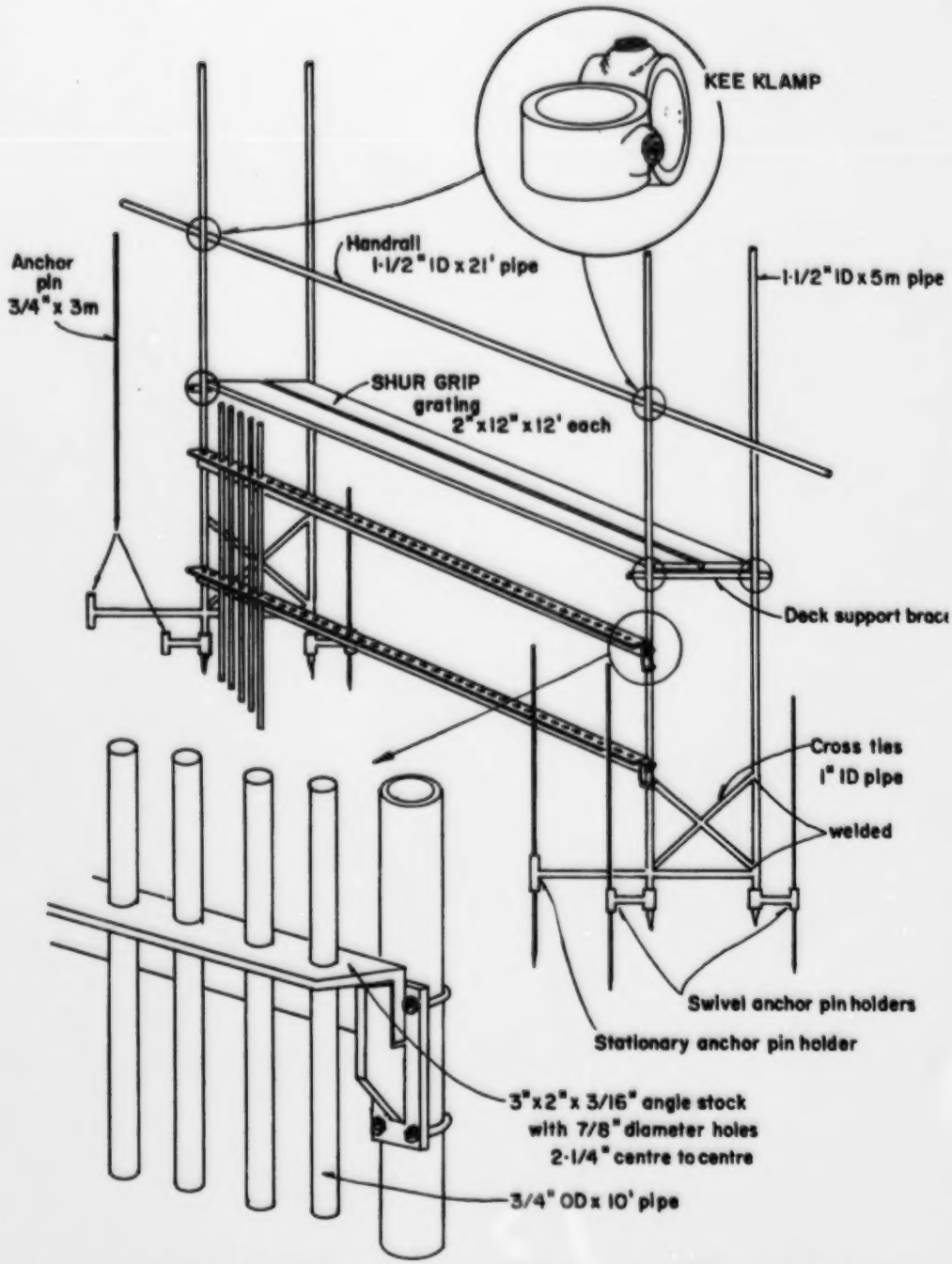

Fig. 4. Three dimensional view of one stationary fence section equipped with adjustable height deck support braces, non-slip walkway grating and anchor pin holders. All pipe connections are made with KEE KLAMP pipe fittings.

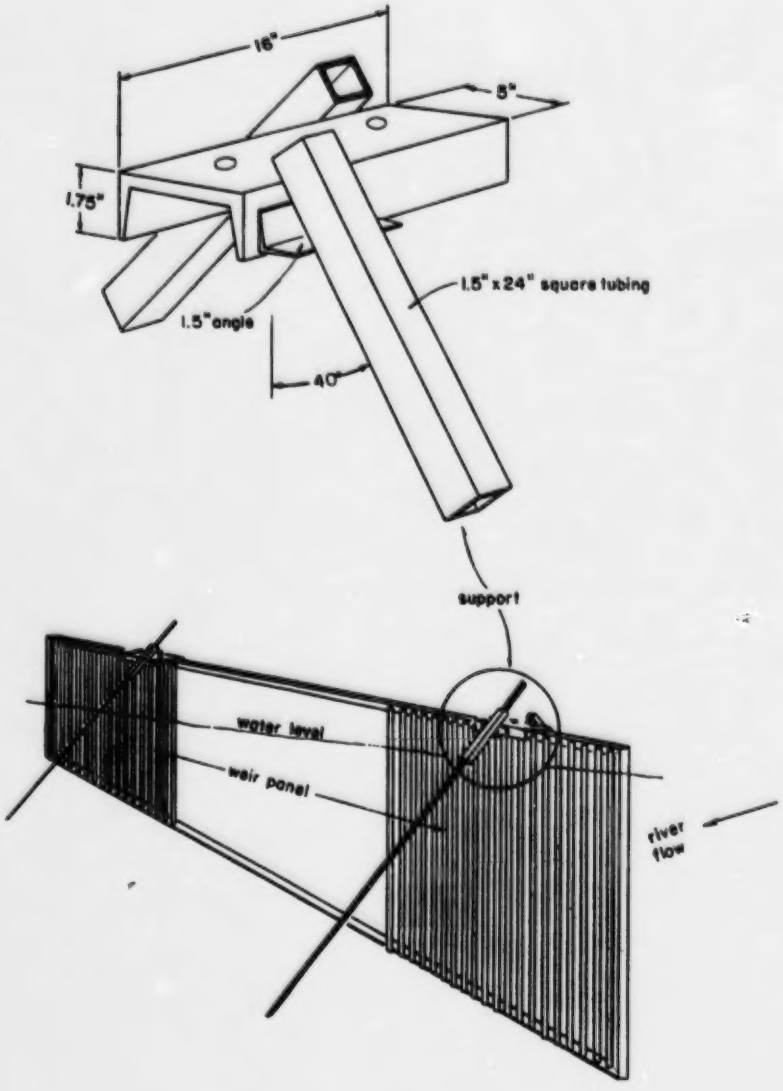

Fig. 5. Three-dimensional view of a stationary fish deflection weir. The enlarged view shows a support bracket that bolts to the top of the weir and holds a steel anchor pin.

4.2 TRANSDUCER-TO-WEIR BRACKET

The transducer-to-weir bracket is an aluminium bracket mounted to the upstream side and shoreline end of the fish deflection weir. Use of the bracket provides the ability to maintain an established acoustic beam configuration with the river and the fish deflection weir whenever equipment moves are made. It features three stabilising jacks for supporting the bracket onto the river bottom and eliminates the vibration caused by current flow (Fig. 6). Excessive vibration in the transducer can create a higher background noise level that may decrease the signal-to-noise ratio. The bracket is also equipped with a levelling bubble easily adjusted with the stabiliser jacks to align the beam horizontally to the river bottom. The bracket has two main components: 1) a horizontal section which connects the bracket to the fish deflection weir, and 2) a transducer assembly which can be moved along the horizontal section to allow the operation of transducers with different beam widths. The transducer assembly houses the transducer-aiming unit, two of the stabilising jacks and the levelling bubble. A complete description of the construction and a materials list is available in Enzenhofer and Cronkite (1998).

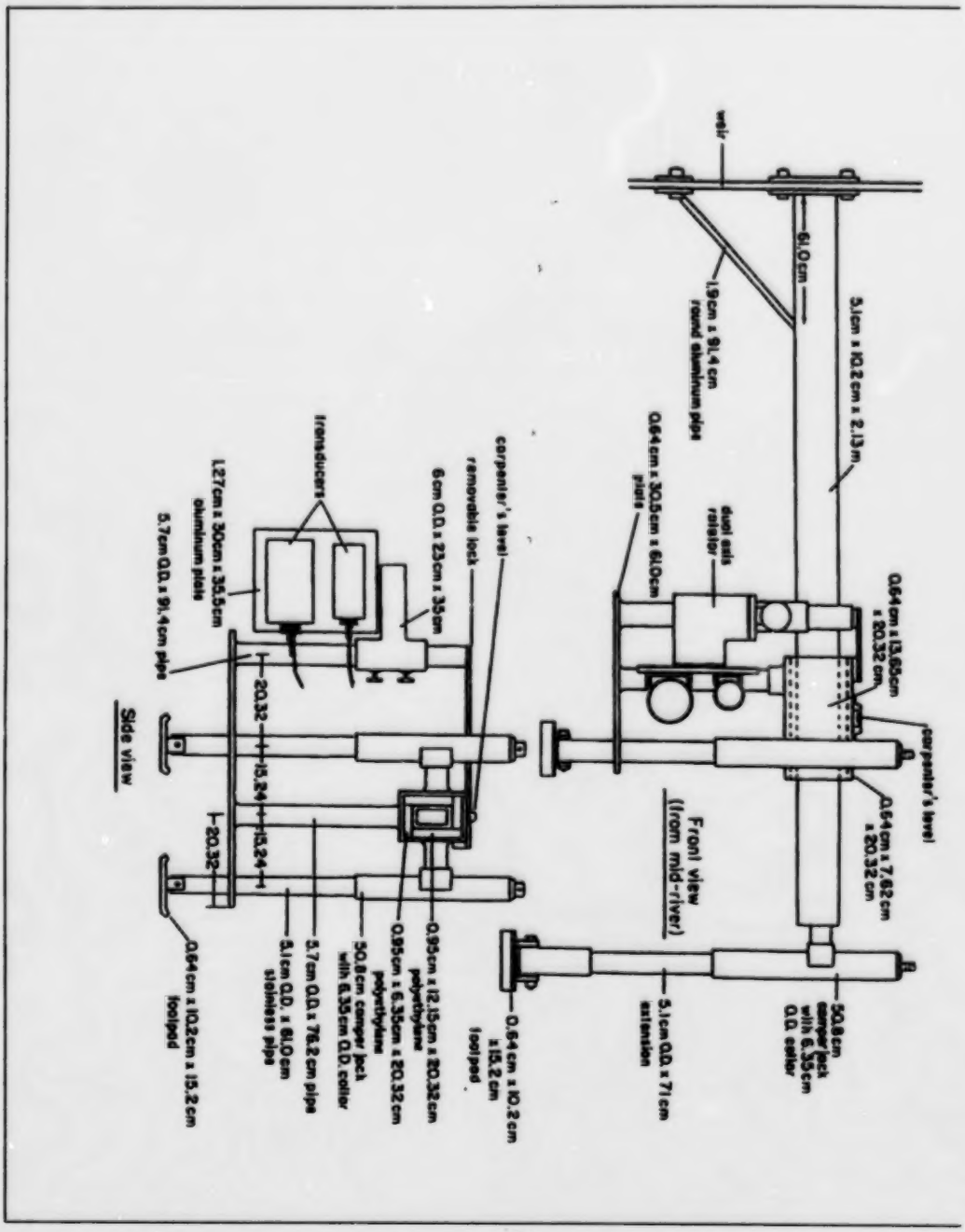

Fig. 6. Schematic of the transducer-to-weir bracket showing a front view of the main horizontal section and transducer assemblage. The side view shows the transducer assemblage alone.

4.3 TRANSDUCER-AIMING UNIT

The transducer-aiming unit (Fig. 7) consists of channel brackets to house the transducer(s), a transducer mounting plate, and a dual axis rotator attached to a gooseneck holder. The gooseneck holder will clamp onto the vertical stanchion of either the transducer-to-weir bracket (Fig. 6) or the tripod (Fig. 8) used for supporting the transducer–aiming unit in the river. A separate bracket has been added to the transducer mounting plate to install an underwater instrumentation package (attitude indicator) capable of displaying (on a PC and monitor) the pitch, roll and tilt angles as well as compass bearing of the instrument (see Sec. 4.6). The underwater instrumentation package is useful when operating in deep or turbid water that does not allow visual observation of the equipment orientation in the river. A cable connecting the rotator controller to the rotator allows the user to remotely activate the rotator vertically and horizontally in order to aim the transducer(s).

The transducer is mounted to one of the channel brackets with stainless steel pipe clamps after the horizontal and vertical axes have been aligned with the transducer mounting plate. We used transducers supplied by HTI, which have markings on the back referencing the left, right, up and down axis positions. Keeping the transducers, channel brackets and bracket mount for the attitude indicator parallel to the transducer mounting plate ensures that the direction that the transducer is aimed is always known.

4.4 TRIPOD (AN ALTERNATIVE TO THE TRANSDUCER-TO-WEIR BRACKET)

The tripod is a free standing aluminium structure that is anchored to the riverbed with steel rods and has a stanchion for attaching the transducer-aiming unit (Fig. 8). It would replace the transducer-to-weir bracket previously discussed for deploying transducers in a fixed location acoustic site. This structure could be used when water levels do not fluctuate often and acoustic equipment could remain in place for extended periods. Generally, a fish deflection weir would still be required to keep fish away from the near field of the transducer beam. However, if the fish passage is offshore, the tripod could be used alone.

Each leg of the tripod has a vertical post with a locking wing nut that houses an anchor rod. Anchor rods are driven into the substrate and adjusting the distance from the top of each vertical post to the water surface levels the tripod. All measurements, such as the placement of the tripod with respect to a weir, distance from shore, or alignment to the river bottom, must be done manually each time the equipment is repositioned.

The tripod can also be deployed in deep-water locations simply by eliminating the use of the anchor rods and attaching a steel plate (25 Kg) to the bottom centre of the tripod's base plate. A cable attached to the top of the stanchion post, operated from a winch and booms installed onto a boat, is used to deploy the tripod. Various releasable cable hooks are available to allow the tripod to be left in position. A safety/recovery line must be attached so that the tripod can be recovered at a later time. Since the equipment would not be visible once set onto the river bottom, the orientation of the transducer beam becomes a challenge. This problem can be eliminated by the use of the underwater instrumentation package attached to the transducer-aiming unit (see Sec. 4.6).

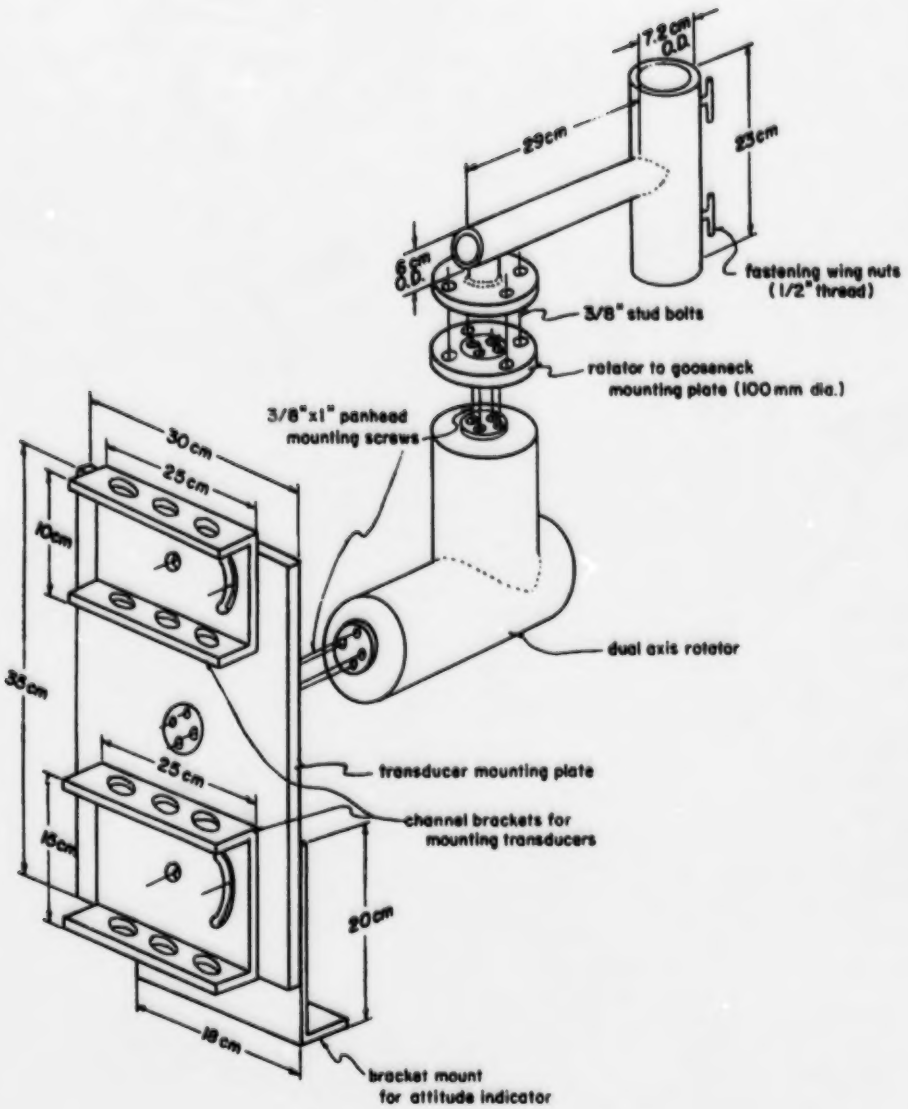

Fig. 7. Exploded view of the transducer-aiming unit.

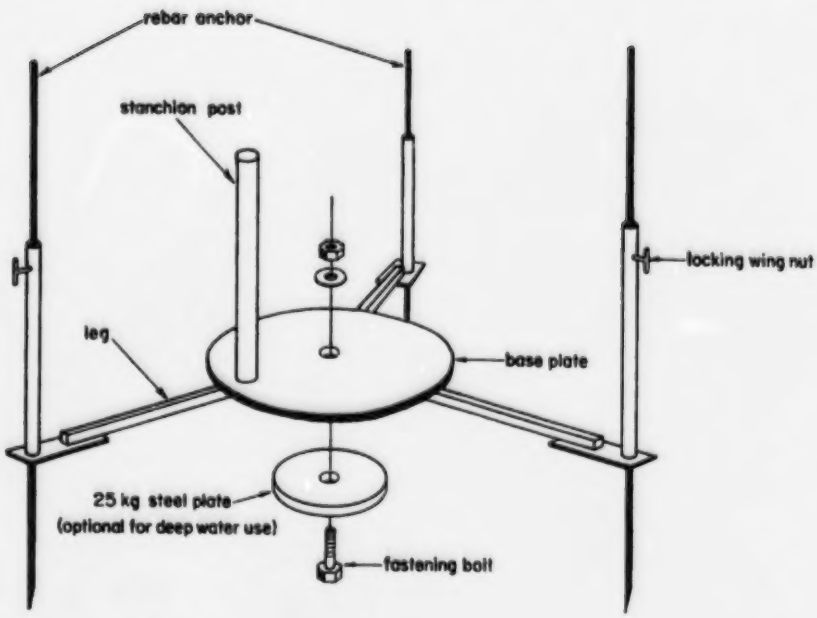

Fig. 8. Three dimensional view of the tripod showing the three anchor pins and locking anchor pin holders, the stanchion post and the optional steel plate for deep water deployment.

4.5 REFERENCE TARGET FRAME

The reference target frame is an aluminium frame that allows precise vertical and horizontal movement of an attached acoustic target (Enzenhofer and Olsen 1997). Shown in Fig. 1 the frame is mounted on the upstream side and at the deep end of a fish deflection weir and is operated in the far field of an acoustic beam. The transducer beam axis is aligned perpendicular to the frame and towards the frame centre.

The main frame body is open at the upstream end and consists of three support members (Fig. 9). This design meets several operational requirements. First, it allows the frame body and target to be at the same range from the transducer. This eliminates the possibility of acoustic noise being created by water flow around an upstream vertical support member, which would interfere with the return signal. Second, we can tilt the entire frame body from a bottom pivot point attached to a support structure. This feature allows us to test for the presence of transducer side lobe activity that can impact the detection efficiency of a transducer. Third, the frame is easy to re-deploy when fluctuating river levels necessitate frequent repositioning of equipment. Finally, the cables that control the position of the target and corresponding target to frame measurements are easily adjusted by one person.

The split-beam system should have software that can display the XY position of a target in the beam cross section in real-time (see Sec. 5.1). Having this feature enables the operator to precisely aim the transducer beam referenced to a target with known position in the water column.

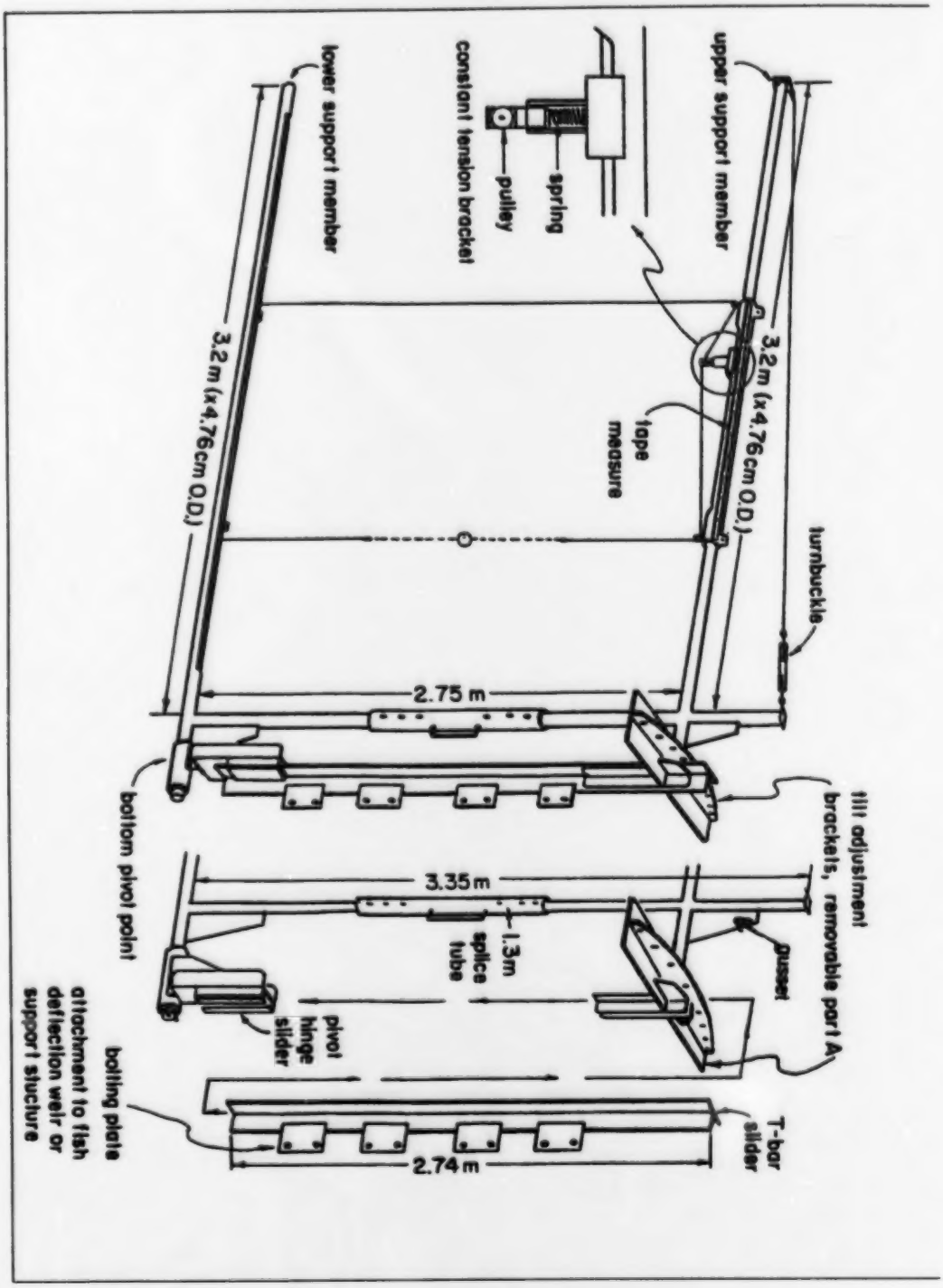

Fig. 9. Schematic of the adjustable reference target frame.

4.6 UNDERWATER INSTRUMENTATION PACKAGE TO AID THE AIMING PROCEDURE

The addition of an underwater instrumentation package will assist in determining the transducer beam orientation in the water. Having knowledge of the beam configuration is important when; 1) aiming the acoustic beam; 2) using multiple aims to cover the water column; 3) working in turbid or deep water, and 4) operating near boundaries such as the surface and bottom.

The electronic compass sensor module produced by Precision Navigation, Inc. from Mountain View, California, USA outputs compass heading, pitch and roll readings via electronic interface to a host system (TCM2 Electronic Compass Module User's manual, 1995). JASCO Research Ltd. of Brentwood Bay, British Columbia, Canada has incorporated this unit into an Underwater Instrumentation Package (UNWINSTRU). The package is housed in a pressure case connected to a cable that has a 6-pin underwater connector at one end and a serial port connector and power lugs at the other end. JASCO Research has also added a pressure sensor and temperature probe to the unit, all of which produce displays on a single screen containing pull-down menus for log file control and program information under a Microsoft Windows application.

The UNWINSTRU package is installed on a bracket that has been added to the transducer mounting plate, which is part of the transducer-aiming unit (Fig. 7). This bracket allows the underwater instrumentation package to be aligned with the transducer so that both have a common vertical and horizontal axis. Readings displayed by the electronic compass sensor module indicate the position of the transducer, an important feature especially when the equipment cannot be seen.

4.7 ADJUSTABLE CABLE REEL

The adjustable cable reel was designed to handle large spools of cables required to operate the transducers, the dual axis rotator and the underwater instrumentation package. Some of these spools are up to one meter in diameter containing 150 m of thick cable, which are cumbersome to work with. Figure 10 shows a simple stand that can be adjusted to fit a variety of spool diameters and that is easily operated from the riverbank or off a boat deck.

The reel is constructed in three main pieces: the centre shaft with one adjustable collar and one pipe thread collar; and two triangular leg stands containing polyethylene pillow block bearings. The centre shaft is placed through the cable spool up tight against the adjustable collar. The other collar with tightening handles is screwed onto the threaded shaft. The centre shaft with attached spool is then placed onto the leg stands and secured with the top portion of each pillow block bearing.

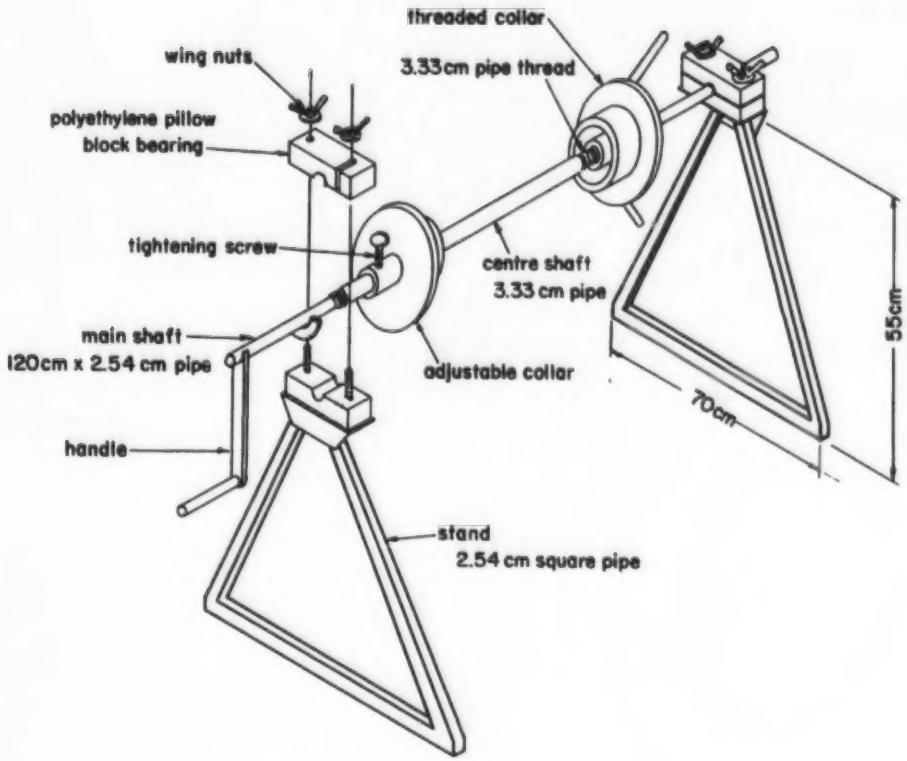

Fig. 10. Schematic of adjustable cable reel.

5.0 ACOUSTIC SYSTEM

Several companies such as Hydroacoustic Technology Inc., Biosonics and Simrad produce scientific quality hydroacoustic systems that are capable of being used to monitor fish passage. This manual describes a split-beam system that contains software supplied by the manufacturer as well as software developed by our group for post-processing and editing acoustic data.

5.1 DESCRIPTION OF THE SPLIT BEAM SYSTEM

The system used at the Qualark Creek facility was an HTI Model 240 Digital Split-beam Hydroacoustic System (Hydroacoustic Technology, Inc. 1993a, 1993b). The acoustic system includes: three-dimensional target tracking software, a 200 kHz Model 240 digital echosounder (DES), a monitor and keyboard, an oscilloscope, a chart recorder, a digital-audio tape recorder, a 486 DX computer equipped with a Model 340 digital echoprocessor (DEP) board, a dot-matrix printer, and a rotator controller (see schematic Fig. 11).

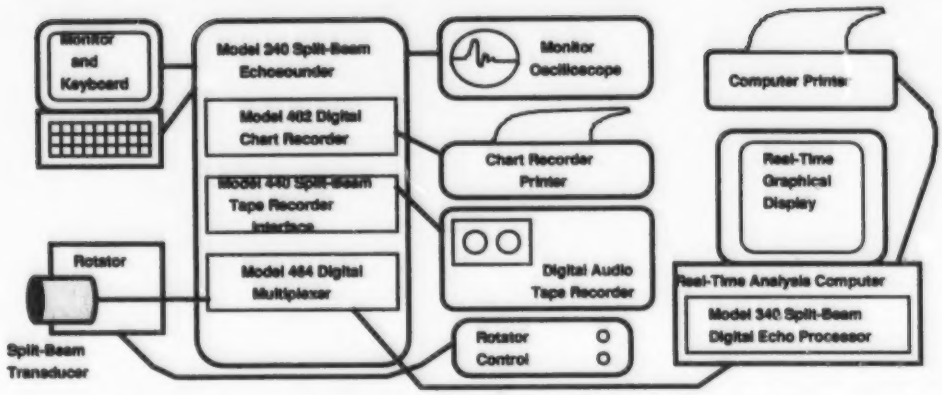

Fig. 11. Schematic of the model 240 split-beam hydroacoustic system provided by Hydroacoustic Technologies Inc., Seattle, Washington (From HTI, 1993).

The receiver contained in the split-beam echosounder provides simultaneous 20-log(R) and 40-log(R) time-varied-gain output, so echo-integration and individual target tracking can be accomplished concurrently. The digital split-beam processor board (DSBP) processes signals received from the split-beam echosounder. This board interfaces with the 486 computer attached to the echosounder and runs the real-time software and stores data files collected during echosounding. Integral to the software that HTI provides are TRACKER/INTEGRATOR that performs target tracking and echo integration simultaneously. These two programs multitask under the DesQView operating environment, processing output from the DSBP board and producing output in the form of ASCII data files and real-time graphical displays. One of the most important real-time graphical displays available is the XY projection. This display shows the target's vertical and horizontal position within the beam cross section. This feature is extensively used during the transducer aiming procedure (see Sec. 7.1) and during acoustic experiments outlined in Sec. 5.2.3.

The dot-matrix printer is the output device for the digital chart recorder in the split-beam echosounder and is used to record echograms. The keyboard and monitor connect to the echosounder and are used to control the echosounder and chart recorder settings. The digital audio tape recorder records raw echosounder output on tape. Tapes can later be reprocessed through the echosounder, using modified system parameters if desired. The oscilloscope displays the return signal voltage vs. time and aids in aiming the acoustic beam and monitoring the system.

Data from single-target echoes are processed by the echoprocessor and written to a computer file. This file is then further processed by the real-time tracking algorithm contained within the Model 340 DEP to indicate those echoes that grouped into reasonable trajectories for migrating fish. The transducer transmits simultaneously on all four split-beam quadrants, but receives the return signals from the four quadrants independently (Traynor and Ehrenberg 1987). Signals from the four quadrants are amplified and combined by the echosounder to form four, half-beam components: up, down, left, and right. The echoprocessor used to calculate the vertical and horizontal off-axis angles for an echo uses the shift in the phase between these four components. Thus, three-dimensional position data is measured for each echo. Knowing the position and associated time for each echo permits estimation of direction of travel, target speed, and target strength. In order to be classified as coming from a migrating fish, echoes have to satisfy the user selection criteria set within the echoprocessor software. First the echo has to exceed a predetermined signal strength threshold that is based on the minimum side aspect target strength for the fish of interest. Second, echoes from potential fish must be detected a minimum number of times in order to be distinguished from the background noise. The minimum number of echoes is partly dependent upon the pulse repetition rate (ping rate) that is set for the echosounder. Third, each returning echo for a

potential track has to meet a pulse width acceptance range to be classed as an echo coming from a single target.

It is possible to process the data that meet the single echo criteria with an automated tracking algorithm other than the one contained within the HTI hydroacoustic system. There are many variations of how an automated tracking algorithm is configured to handle fish trajectories or track multiple fish in the acoustic beam. For this reason we will not cover the use of other tracking algorithms since they may be the property of individual organisations. As more tracking algorithms are being developed the literature on their specifications will become available. Several tracking algorithms are currently well documented and are used in areas such as radar tracking (Blackman 1986). These algorithms are applicable to acoustic fish tracking and can be adapted for use.

Another requirement for data analyses is an editing software package which allows the quick removal of unwanted tracked data which may occur from noise events or incorrectly tracked fish data. The editor should also be able to create tracks from echoes deemed as coming from a fish but that were miss-tracked by the automated tracker. An example of this type of software, used in conjunction with data produced by the split-beam system, is *HAFU as* described by Olsen (1995). Other editors that we have used are described in Carousel Computer Consultants (1997) and Xie (1999).

5.2 SELECTION OF AN APPROPRIATE TRANSDUCER

Selection of an appropriate transducer should be made after investigating several factors. Some factors will be obvious and can be addressed once a reconnaissance survey has been made.

5.2.1 The physical properties of the river

The depth of the river to be monitored will play a role in determining the nominal beam width (-3dB) that could be selected. The acoustic beam must fit within the water column for the range of interest without exhibiting interference from the water surface or the river bottom. The existence of surface or bottom signals could mask the signals from fish.

Example:

To determine the vertical height of an 8° circular transducer at 10 meters range

Tangent a = (Opposite/ Adjacent)
Beam diameter = 2(Range*Tangent (a/2))

Solution:

Tangent 8°/2 = 0.0699
Range = 10 m
Beam diameter = 2 ((10 m) (0.0699)) = 1.398 meters

If the flow rate is high the use of wide beam transducers such as a 15° circular beam may be inappropriate because of the high background noise levels which may be present. Beam geometry experiments done in situ (discussed in Sec.5.2.3) can determine the probability of detection for a target placed in the far field of the transducer beam as a function of the off-axis angle. We found that our wide beam circular transducers had poor detection probability even within the –3dB beam width. This means that the transducer will have poor detection off axis, which will limit the ability to detect fish passage near the edge of the beam. It is advisable to check a potential site with the acoustic system to be used along with several leased transducers before making final selections.

5.2.2 Fish passage location

If fish passage occurs near the river bottom, an elliptical transducer is better suited to detect their passage than a transducer with a circular beam (Enzenhofer et al. 1998). Use of an elliptical transducer will allow the beam to be placed closer to the river bottom and will provide a greater horizontal cross sectional area of the beam for fish to pass through.

If fish passage occurs at increased ranges from the transducer, then vertically narrower elliptical beam transducers will improve fish detection. For example a 2° x 10° elliptical beam is less likely to be affected by surface or bottom noise than a 4° x 10° beam at the same range.

5.2.3 Beam geometry experiments

Beam geometry experiments should be performed to aid in the selection of the appropriate transducers. These experiments are designed to determine the detection characteristics of the acoustic system and transducer combination. It is important to perform these experiments in-situ, as they will help determine the acoustic system's ability to detect fish above the background noise present in the river. Several types of experiments that can be used are:

- Routine system calibration with a standard reference target.
- Beam map procedure that defines the probability of detection for a target based on its position within the beam cross-section.
- Target tracking experiments that test the acoustic system and tracking algorithm as a target is systematically passed through the beam.

5.2.3.1 Procedure for suspending targets in the acoustic beam:

A common method used to suspend an acoustic target into the transducer beam is by attaching it to monofilament line suspended from a long pole and lowering it into the beam. This method may be adequate to perform routine system calibration checks with a standard reference target; however, it will be difficult to perform other beam geometry work. Holding a target stationary or simply finding the target in the beam is difficult to do in fast flowing rivers. For this reason the reference target frame was developed (see Sec. 4.5). Whichever method is used to deploy the target, a cradle, which encompasses the target, is required for attaching the target to the long pole or to the bridle on the reference target frame. Fig. 12 shows the construction of a cradle, made from monofilament fishing line or net twine, that can be used to contain the standard target spheres or other acoustic target spheres.

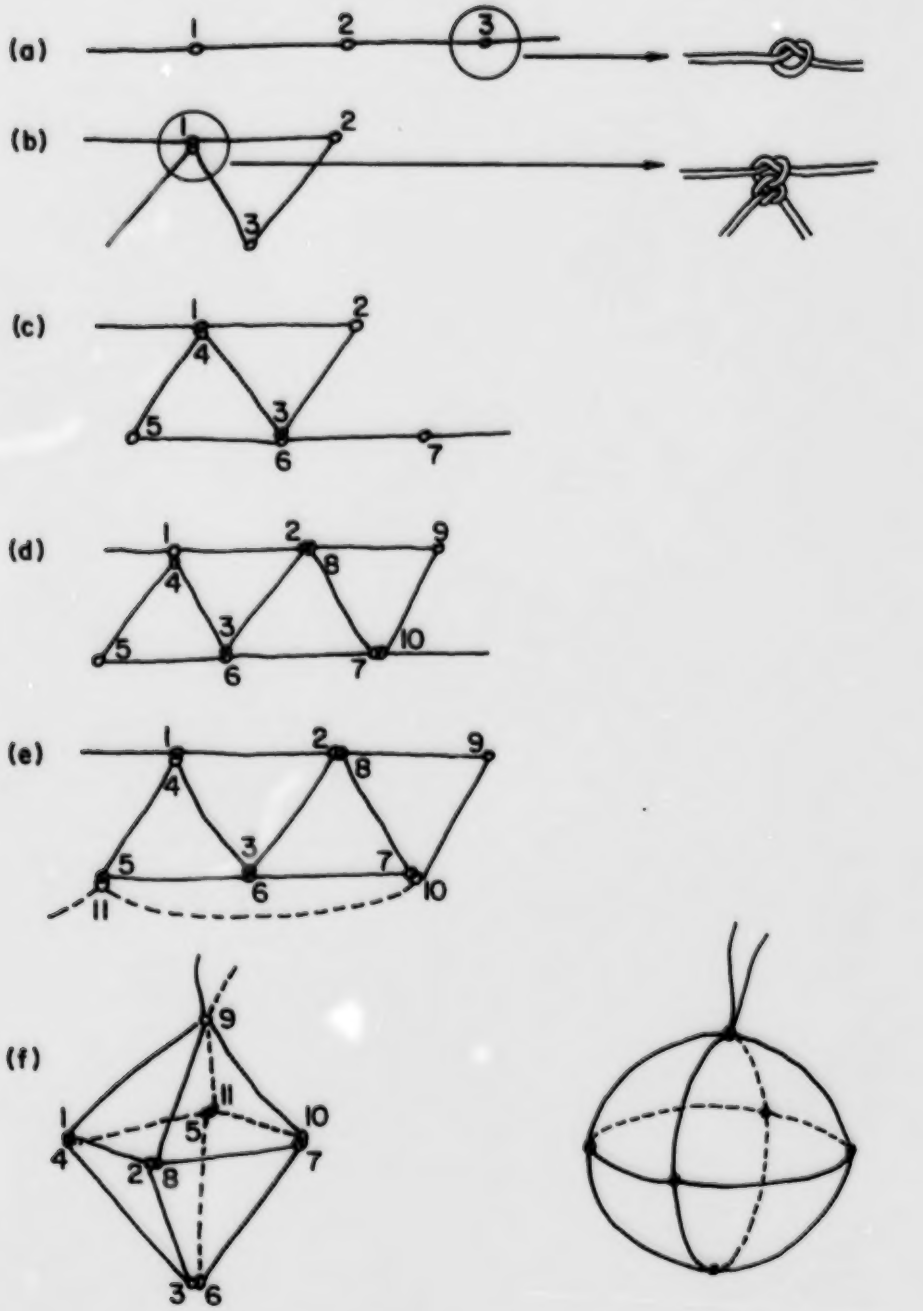

Fig. 12. Construction of a cradle to encompass spherical acoustic targets. The numbers show the order of tying knots that are one quarter of the sphere circumference apart.

5.2.3.2 Routine system calibration

We test the overall receive and transmit components of the hydroacoustic system by collecting *in situ* target strength data from a calibrated sphere attached to the reference target frame. For a 200 kHz HTI Model 240 split-beam, system a 38 mm tungsten carbide sphere (-39.55 dB) is placed on the beam axis beyond any near field effect. By checking the performance of an acoustic system with the calibrated sphere, we can investigate the following points that will assist the transducer selection process.

We can test the ability to detect a small target as a function of its position within the beam. At what point will the target no longer be detectable and simply disappear in the background noise level?

Transducer sensitivity can vary between transducers due to differences in their construction. Between transducers of the same beam width, one transducer may be better suited to detect targets in a noisy environment.

The accuracy of calibration documents can be verified to some extent by comparing the observed values during a routine calibration with those provided by the manufacturer. During this process it is important to check the acoustic system and tracking parameters which have user input. Often a discrepancy can occur in expected target strength values merely because of an incorrect value inserted during the system set-up phase. We have had several experiences where the calibration documents provided were incorrect due to human error in transposing the data. These errors can have large effects on the data gathered by the system, but can usually be detected by testing with a standard target. Large errors of more than ±1 dB in target strength values will alert the operator to a possible problem.

5.2.3.3 Beam map procedure

We use the split-beam system's three-dimensional tracking ability (Ehrenberg 1982) to produce a beam map that defines the probability of detection for a target based on its position in the beam cross section (Mulligan and Kieser 1996). This procedure can be done with a calibrated standard target, a freshly killed fish, or a plastic sphere that returns the same signal strength as an adult salmon. We attach the target to the reference target frame and record data for a number of positions in a grid pattern that covers the entire beam cross-section. The acoustically determined position for each grid point is then compared to the same grid position measured with the frame.

Example:

A beam map was made with a 200 kHz Model 240 digital echosounder with an 8° circular transducer using a 10.0 cm plastic sphere target. The echosounder was operated at 25 dB transmit power and –18 dB total receiver gain. The transmitted pulse width was 0.2 ms at a pulse repetition rate of 10 pings per second. We used a maximum of 0.3 ms and a minimum of 0.1 ms pulse width acceptance criteria for the echo signal. The acoustic signal was amplified with 40Log(R) time-varied-gain. A minimum echo amplitude threshold of 200 mV (corresponding to target strength of –40.5 dB) was used to reduce the affect of background noise. We recorded 8 minutes per position, at a range of 3.7 m from the transducer, for a potential of 4800 echoes per position. These settings are the same as those used for enumerating salmon at the Qualark Creek site. The following steps outline a beam map procedure:

1. The target is attached to the frame using the cradle outlined in Fig. 12.

2. The target is placed on the beam axis by following steps 1-5 of the standardisation of the aiming procedure (see Sec. 7.1)

3. Acoustic data are recorded on the beam axis position for a set period of time and denoted as the first position (POS. 1).

4. The target is moved vertically on the frame and the distance moved vertically is recorded (POS. 2). This procedure is done above and below the vertical beam axis position towards the edge of the beam, until the target falls below the minimum amplitude threshold set for the target-tracking program.

5. After a vertical run of the acoustic beam is completed the target is returned to the beam axis position and then moved right or left in the horizontal direction. The distance moved horizontally is recorded.

6. Another vertical run of the beam is then made. This procedure is done until the entire cross section of the beam is covered resulting in a true target to frame co-ordinate position with an acoustically determined co-ordinate for each position.

7. By reviewing the *.RAW (see Sec 9.0) file the total number of received echoes is recorded to obtain a detection probability for each position (Fig 13 (Top)).

$$\text{Detection probability} = \frac{\text{Total echoes received per position}}{\text{Total pings transmitted per position}}$$

8. By reviewing the *.ECH file the mean acoustic horizontal position (X) and the mean vertical position (Y) is plotted for each position. These are then overlaid onto the actual XY position measured with the reference target frame for each position. All frame measurements are referenced to the frame axis, which coincides with the acoustic axis. An example of the 8° 200 kHz transducer is shown in Fig. 13 (Bottom).

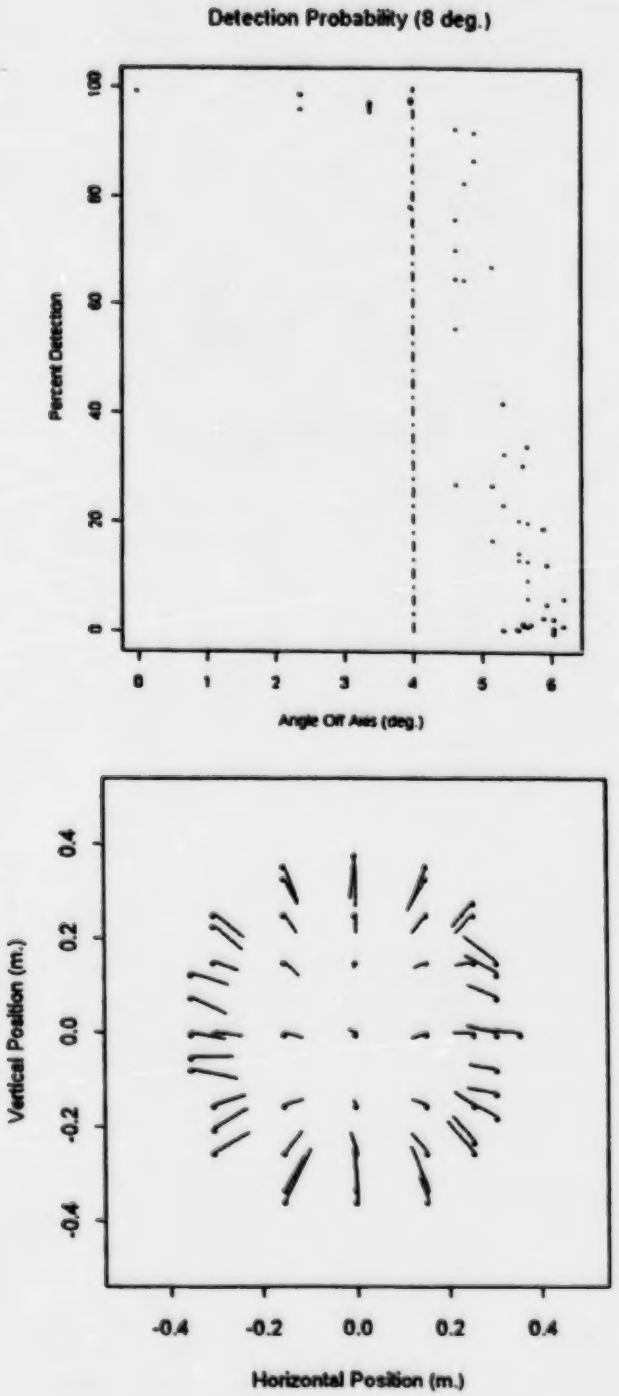

Fig. 13. Results of a beam map for an 8° split beam 200kHz transducer using a 10.0 cm plastic sphere at 3.7 m range. (Top) Probability of target detection vs. off-axis angle. The dashed line represents the nominal beam width at –3dB off-axis. (Bottom) Comparison of the split beam acoustic position vs. the actual target frame position. The solid dot (•) represents the true position of the target. The end of the corresponding line (-) represents the acoustically determined position.

5.2.3.4 Target tracking experiment

We can test the ability of the combined hydroacoustic system, the transducer and the automated target-tracking algorithm to track a target passed horizontally through the acoustic beam. The ability to track a linearly moving target through a cross-section of the beam is a function of the cord length of the beam (the horizontal distance across the beam at that cross-section), the speed of the target, and the detection efficiency of the transducer used.

Example:

A target tracking experiment was done using 200 kHz Model 240 digital echosounder with a 4° x 10° elliptical transducer and an 8° circular transducer. The echosounder was operated at 25 dB transmit power and –18 dB total receiver gain. The transmitted pulse width was 0.2 ms. A lead-filled plastic sphere target (10.0 cm diameter) returning similar signal strength as an adult salmon (-31 dB) was used. The pulse repetition rate was adjusted to simulate an average fish swim speed (1.0 meter per second) for the target as it was passed through the beam cross-section. The following steps outline the target tracking experiment:

1. The parameters for the target-tracking algorithm were set the same as for fish tracking. In order to be classified as coming from a tracked target, we used a minimum echo amplitude threshold of 200 mV, equivalent to target strength of approximately –40 dB. For a 0.2 ms transmitted pulse width, we used a maximum of 0.3 ms and minimum of 0.1 ms for the echo signal. A minimum of four accepted echoes, none having more than a seven-ping gap between echoes.

2. The lead-filled plastic sphere target was suspended from a float using net twine and was passed through the acoustic beam guided by a tether line assembled off the end of the fish deflection weir (Fig. 14).

3. The distance from the target to the buoy was adjusted to allow the target to pass through the horizontal axis of the acoustic beam. Once this location was found the target was passed through the beam 100 times with each pass recorded by the hydroacoustic system.

4. The target was raised vertically, the distance moved recorded, and another session of 100 passes of the target made. This was repeated until the target was no longer detected.

5. By reviewing the *.ECH or the *.FSH file, the number of tracked targets recorded by the digital echoprocessor for each vertical position can be obtained.

This experiment was done using only one target suspended from the float, but it would be simple to deploy more than one target from the same equipment. By passing several targets through the beam at the same time, a test of the ability of the system to detect multiple targets is possible.

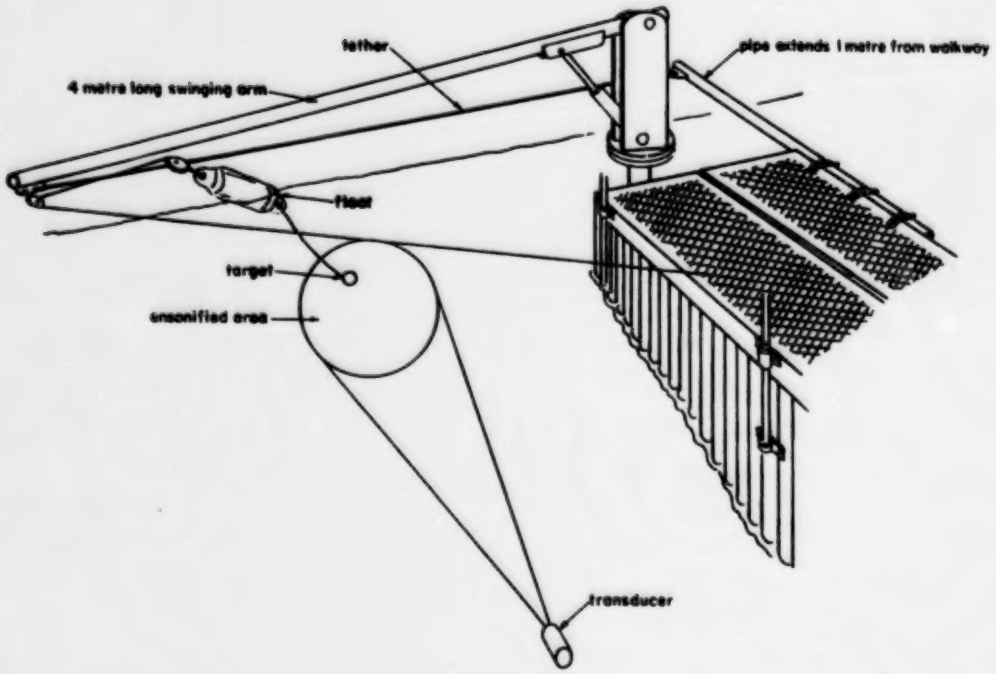

Fig. 14. Configuration of equipment used to conduct a target tracking experiment. A target suspended from a float is passed through the acoustic beam by travelling along a tether line.

5.3 ACOUSTIC SYSTEM MALFUNCTION

New acoustic systems tend to be stable over time and generally produce reliable acoustic data. However, malfunctions do occur which can severely impact the system's ability to function. Identifying the nature of a problem or pinpointing the specific piece of equipment that produced the failure can be difficult. To list all the possible causes of malfunctions would be an onerous task. Instead, we attempt to identify system malfunctions by following a process of elimination of the system components that include; the software component, the electronic equipment, the transducer cables, the transducers, and in-river equipment used to aid the hydroacoustic measurement. As a precaution, we always suspect ourselves first and check any entries we have input into software that operates the acoustic system. Once satisfied that it is not simply an input error, we then suspect the equipment.

Some system failures are obvious, whereas others may not be noticed until some later point in the data collection. It is advisable to adopt a routine of performing regular system calibrations using a calibrated reference target. These calibration checks will test the overall transmit and receive components of the hydroacoustic system.

Note:

The calibration check only gives the status of the acoustic system for the location that the target is placed within the beam. Several positions throughout the beam cross-section are required to test the

function of the three-dimensional target tracking software or to determine detection characteristics throughout the beam.

The occurrence of a malfunction in the acoustic system is usually first noticed during one of the following time periods.

- During the initial start up of the acoustic system software
- During the data collection process
- During the processing stage of the collected acoustic data

5.3.1 Malfunctions during the initial start up of the acoustic system

This is the most common time that we experience problems in operating the hydroacoustic system. Most often, failures are due to user-input errors to the software programs that control the digital echosounder or the digital echoprocessor. A review of the appropriate files that may have been changed to start a new data collection process is the first step. For example, data produced by the echoprocessor is written to a named directory on the hard drive of the PC. If the named directory does not exist on the chosen drive, the acoustic system will not operate.

A review of the cabling instructions that link the electronic components together as well as a check for poorly connected cables should be made. If all else fails, then a review of the equipment manual supplied by the manufacturer may help.

Finally, monitoring the oscilloscope during any data collection period is an important step to follow. By viewing the returned signal from the echosounder as well as the processed signal from the echoprocessor, we can determine if the background noise is too high, if an inappropriate processing range has been selected, or if the system is operating at all.

5.3.2 Malfunctions during the data collection process

Problems that occur when the acoustic system is operating usually involve a failure in a component of the hydroacoustic equipment. To pinpoint the component involved largely depends on the degree of the failure. It must be determined whether equipment in the water or the acoustic components on shore are involved. Rather than list all the possible malfunctions we will list two examples that were encountered during the work performed at the Qualark Creek site and the approach used to troubleshoot.

5.3.2.1 Example 1:

During a beam map experiment to determine the detection characteristics of a transducer, it was noticed that the returned signal was –5 dB smaller than expected for a target deployed with the reference target frame. Also the targets acoustically determined position, while viewing the real-time graph display of the beam cross-section (XY), was considerably offset from the actual target to frame position.

Procedure used:

1. We reviewed the software that controls the transmit and receive input values used by the acoustic system. For example, an improper entry for the receiver gain or source level could easily account for the –5 dB discrepancy in the signal strength. Improper slope values for the vertical or horizontal electrical to mechanical angle ratio could cause the improper acoustically determined target position.

2. We placed the target back to the beam axis position by rotating the transducer with the dual axis rotator and viewing the real time XY graph display. A horizontal sweep of the target was made with the transducer to cover the entire horizontal beam width. This was done to test the alignment of the transducer to the river bottom and target frame and to determine if the beam was asymmetric.

3. We suspected the transducer was faulty, but the echosounder to transducer cable had to be eliminated as a possible source of trouble. The cable connection between the transducer and the DES was checked.

4. A second digital echosounder, calibrated with the cable and transducer being tested, was substituted for the original echosounder.

5. A second cable, of equal length as the original, was switched with the original DES and the transducer to eliminate the cable as the problem source.

6. A second transducer was tested with the original system and at this stage the hydroacoustic system functioned properly. This process pinpointed the problem to be in the transducer that required repair by the manufacturer.

5.3.2.2 Example 2:

We monitor fish passage using an elliptical transducer to cover the water column with multiple aims that are controlled by software in the digital echoprocessor. The program activates a remote controller that moves a dual axis rotator to which the transducer was attached. An hourly aiming sequence is used. Each hourly sequence consisted of transducer aims with equal time duration, stacked vertically from the river bottom to the surface, to cover fish passage. Ranges were set according to the bottom signal present for each aim. We also used an underwater instrumentation package (see Sec. 4.6) mounted to the transducer mounting plate (see Fig. 7). During one recording session, we noticed the acoustic system was operating, but the bottom signal did not appear to change when the transducer moved to the next aim above. This caused the acoustic system to track a large amount of bottom signal due to incorrect range information.

Procedure used:

1. We reviewed the program software and then restarted the acoustic system to begin a new aim sequence.

2. The tilt angle displayed by the underwater instrumentation package was monitored when the system moved the transducer from the bottom aim to the next aim above. The tilt angle did not change between aims.

3. Cable connections from the acoustic system to the remote controller were checked. The rotator control cable connecting the dual axis rotator and the remote controller were checked. The system was restarted between each successive cable check.

4. At this stage the dual axis rotator, which physically moves the transducer mounting plate, was suspected of failure. First, the remote controller and the rotator cable were eliminated as being the problem.

5. We substituted a second remote controller into the system and restarted the aim sequence. The problem persisted.

6. We substituted a second rotator cable with the rotator controller being tested to eliminate the cable as the source of failure. The problem persisted.

7. At this stage a second dual axis rotator was substituted into the original system and the unit functioned properly. This process pinpointed the original dual axis rotator as being faulty, requiring repair.

5.3.3 Malfunctions noticed during the processing of collected acoustic data

Recognising a system malfunction from recorded data produced by what appears to be a normally operating acoustic system is difficult. In fact, unless a post-processing tool such as a track editor (see Sec. 9.0) is used, a serious problem may be overlooked. This implies that accepting real time data from an automated tracking algorithm should not be solely relied on without performing periodic checks on the quality of the data. Use of a track editor, capable of displaying the trajectory and signal strength of a tracked fish passing through the beam (Fig. 20); will help in determining proper system function.

Example:

While processing data produced for a 24-hr period at Qualark Creek, using a track editor, we discovered that only a portion of the beam was operating. Fish trajectories would enter the beam and only be tracked in half of the beam cross-section. At times this can occur if the aspect of the fish to the beam causes its signal strength to drop below the threshold value required for an accepted echo. In this case, all fish trajectories ended abruptly. If the real-time data were relied on for this period, then the total number of tracked fish would be incorrect. Potential tracks may not have received enough echoes to satisfy the tracking algorithm leading to an underestimate of passage. A systematic troubleshooting review of the acoustic system components revealed that the transducer was faulty and one quadrant was not producing a signal to the echosounder.

6.0 ACOUSTIC PARAMETERS

The acoustic system parameters can be separated into two categories. First, the parameters which control the transmit and receive components of the hydroacoustic system used to collect the data. These parameters include; transmit power, pulse width, pulse repetition rate, receiver gain and time-varied-gain (TVG). The second set of parameters are those used by the automated tracker to process received echoes.

The target tracking was done in real-time to track the fish ping to ping. Received echoes had to meet several criteria in order to be classified as coming from a fish. First, signal strength had to exceed a predetermined threshold, which excludes the background noise present in the system. Second, echoes from a potential fish had to be detected a minimum number of times. Finally, each returning echo had to meet the pulse width criteria to distinguish the single target fish echoes from echoes coming from multiple targets or background interference.

6.1 TRANSMIT AND RECEIVE SETTING

Manufacturers of hydroacoustic equipment should supply a table listing specifications for the transmit and fixed through system gain values to be used when operating the split-beam system. These values have been determined when the entire system was tested in a calibration facility. The selections of an appropriate transmit power or receiver gain setting will depend on the conditions present during the data collection period. Acoustic work in rivers often results in low signal-to-noise ratio (SNR) which impacts the ability of the system to detect fish. We can improve the SNR by using a narrower beam transducer in rivers where volume backscatter is the dominant noise source.

With the 200 kHz HTI model 240 digital split-beam system we use the maximum source level to transmit power setting listed for a particular transducer and echosounder. This usually means a maximum of 25 dBw for the 4° x 10° elliptical transducers and 8° circular transducers. Care should be taken to follow the manufacturers suggested maximum power ratings for larger beamed transducers as there is a physical limit to the power that can be transmitted through them. For example, a 15° circular transducer is limited to a maximum power output of 20 dBw. The total receiver gain setting is kept to a minimum (-18 dB) in order to minimise the chance of signal saturation and to avoid increasing the noise level.

Increases to the pulse duration should be done with caution as increases to the pulse width limit the ability of the system to detect fish in close proximity to one another. At Qualark Creek we used a transmit pulse width of 0.2 ms for fish passage that was concentrated from 4– 10 m from the transducer.

6.2 PULSE REPETITION RATE (PING RATE)

Selection of an appropriate ping rate for data collection will be dependent upon several considerations. First, the maximum range to be monitored for fish passage will dictate the maximum allowable ping rate. For example, if you wanted to set the range to 70 m, a ping rate of approximately 10/sec. would be the highest rate obtainable. A rate higher than the 10 pings/sec. would not allow enough time for the echo from the first transmission to be received before the next transmission was made.

Secondly, the ping rate should be selected which optimises the tracking ability of an automated fish tracking algorithm. The detection of a fish track is largely dependent upon the time it takes for the fish to enter and exit the ensonified region. Sufficient echoes that meet the single echo selection criteria are required to constitute a fish track. As the ensonified region increases with range, more horizontal distance across the beam cross-section is available to detect fish passage. This infers that the selection of an appropriate ping rate is somewhat controlled by the distance from the transducer that fish passage occurs. Often a faster ping rate is required to accumulate enough accepted echoes when fish passage is close to the transducer.

Example:

We can determine the potential number of echoes from fish passage at various ping rates. For example, using a 4° x 10° elliptical transducer and a fish passing at 2 m range through the horizontal beam axis we would expect the following:

Horizontal beam width for 10°@ 2 m range = 0.35 m (see Sec. 5.2.1)
Fish swim speed (assumed average) = 1.0 meters per second

Then:

@ 10 pings per second the fish travels 0.10 meters between pings
Potential echoes = 3.5

@ 20 pings per second the fish travels 0.05 meters between pings
Potential echoes = 7

The above example shows that a fish travelling through the horizontal beam axis at 2 m range, using a pulse repetition rate of 10 pings per second, may not produce enough echoes to satisfy a minimum acceptance criteria of 4.

When fish passage occurs at further ranges, it may produce excess numbers of detected echoes. These excess echoes may be problematic during heavy passage rates since they will create large quantities of data for the acoustic system to process. With this in mind, the selection of a slower ping rate at longer ranges may be warranted.

6.3 THRESHOLD

Selecting a threshold value will depend on the amplitude of noise present in the detected signal. This can be determined by viewing the return echoes on the oscilloscope during times when fish are not present. We have found that the flux of fish can be large enough to mask the ability to determine the background noise amplitude. In the HTI split-beam system, the selected threshold value must be entered by the user to operate the digital echoprocessor (DEP). The entered value establishes the minimum echo amplitude criteria that the DEP will accept for the target-tracking program.

The DEP can also be configured to apply range-gated threshold values, which allows the user to ignore some stationary targets and process around them. At the Qualark Creek site, the fact that we were working on a flat sandbag ramp minimised the potential of detecting unwanted bottom targets. Fish passage was also at close range to the transducer (<15 m), well within the length of the ramp, which allowed us to use one threshold value for the entire range of interest.

6.4 PULSE WIDTH

We used a transmitted pulse width of 0.2 ms for both the 4° x 10° elliptical and the 8° circular transducers tested at the Qualark Creek facility. A maximum of 0.3 ms and a minimum of 0.1 ms were used for the echo signal as part of the single-target selection criteria used by the target-tracking algorithm. Longer pulse widths were not used as we felt a longer pulse would impact the ability of the system to detect fish that were travelling in close proximity to each other.

7.0 AIMING THE ACOUSTIC BEAM

Knowing the precise aim of the acoustic beam is important to the successful detection of passing fish. Failure to adopt a method of standardising the beam aiming procedure can result in undetected fish. If the beam is aimed too high, the fish can pass under the beam undetected. It is also possible to aim a transducer beam too low and into a sand or silt river bottom when the operator relies solely on the return signal coming to an oscilloscope. The returning signal may appear reasonable to the eye, but in fact a large portion of the lower half of the beam is being absorbed by the soft bottom, resulting in improper beam function or no detection at all. To properly aim a split-beam hydroacoustic system the following is required:

1. The acoustic system should have software which can display a target's vertical-horizontal position (XY) in real-time to a PC monitor.

2. Viewing the return signal coming from a target whose position is known and that is suspended in the far field of the beam.

3. A standardised procedure should be adopted in order to maintain a repeatable beam aim during equipment moves.

7.1 STANDARDISATION OF THE AIMING PROCEDURE

Since the water levels on the Fraser River fluctuated almost daily, equipment was frequently repositioned. The standardisation of the aiming procedure adopted at the Qualark Creek facility utilised the in-river accessory equipment described in Enzenhofer and Cronkite (1998). The equipment consisted of an adjustable reference target frame, an automated fish deflection weir and a transducer-to-weir bracket and was used in conjunction with the HTI Model 240 Digital Split-beam Hydroacoustic System. The aiming procedure consisted of the following steps:

1. An acoustic target having the same signal strength as an adult salmon is attached to the vertical cable of the adjustable reference target frame (Fig. 9). We use a hollow plastic sphere [1](10.0 cm diameter, used in the food industry to provide surface insulation for open vats of liquids) to yield an average target strength of –31dB.

2. The target frame is lowered to its working position and the target is approximately positioned vertically in mid-water. The horizontal position of the target is set to coincide with the distance measured between the centre of the transducer to the fish deflection weir. This places the beam axis parallel to the deflection fence.

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1 United States Plastics Corporation (spheres float on surface of liquid in open tanks and thereby greatly reduce the exposed liquid surface area).

3. The transducer is aimed via a remotely operated rotator (Fig. 6) until the target is located within the acoustic beam, as indicated by the signal monitored on the oscilloscope.

4. Once the target has been located and appears as a steady target on the oscilloscope, the vertical position on the frame is noted. The target is then moved vertically, both above and below the detection range of the acoustic beam, to ensure that the observed signal disappears. If the target does disappear, it can be reset to the recorded vertical position.

5. The target's vertical-horizontal position (XY) is then displayed by software on the PC monitor. The rotator is used to align the acoustic beam until the target appears on the beam axis.

6. The target is lowered to the bottom of the frame, below the beam of the transducer. The transducer is then rotated down vertically until the target echo is observed on the oscilloscope. With the transducer in this position, the target echo should disappear if the target is raised vertically out of the beam. This establishes the bottom-most position for the aim and ensures that errant bottom signals are not detected.

7. The target is moved vertically until it appears on the beam axis of the XY graph screen display. Record the target to frame position and rotator tilt angle.

8. Remove the target frame.

9. Subsequent moves of the equipment will maintain the same beam configuration by rotating to the rotator tilt angle recorded in step 7. Periodic checks of the alignment can be made by re-deploying the target frame with the target placed in the recorded target to frame position noted in step 7. The target should appear on the beam axis of the XY graph screen display.

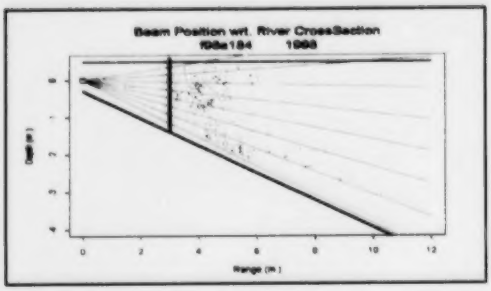
8.0 SAMPLING STRATEGY

Location of fish passage in the river cross section can vary dependent upon many factors such as current flow, water depth, tidal influence, water temperature, water turbidity or presence of fishing activities. Generally, fish passage occurs in areas having the least current flow, which often is within the first meter from the bottom and within 15 m from shoreline. To monitor this type of passage behaviour, a narrow elliptical beam transducer is best suited because it generally exhibits well-defined beam edges, at the –3dB point, and thus, can be aimed close to the river bottom. When this transducer is mounted to a dual axis rotator with a remote controller, the area of fish passage can be sampled with multiple aims. The shore-based transducer is configured to cover the water column with processing ranges determined by the presence of surface or bottom signals. We used a 4° x 10° elliptical transducer to cover the water column in an hourly aiming sequence consisting of aims of equal time duration. Fan plots (Fig. 15) show the cumulative total and passage location of fish within the water column for each 24-hr period (see Sec. 9.0). A fan plot was produced for each day showing the transducer, the number of aims used and the end of the fish deflection weir. Each dot represents the mean position of a fish that was tracked through the beam. For each aim the echo acceptance angle is limited to +2° and –2° from the vertical axis. This is done to avoid overlap of coverage between transducer aims. The upper half of the top aim and lower half of the bottom aim have wider acceptance angles to ensure maximum coverage in those areas.

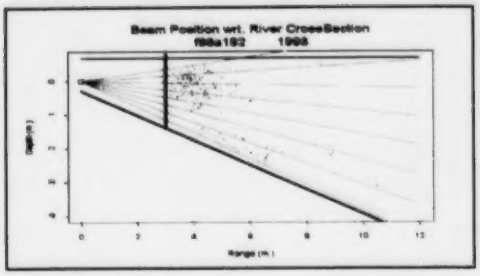
Having the ability to modify the number of aims allows the user to detect changes that may occur during the migration period. We have observed dramatic changes in fish behaviour during high water (Fig. 15) or during in-river activity such as gill net fisheries (Fig. 16).

a). 1998

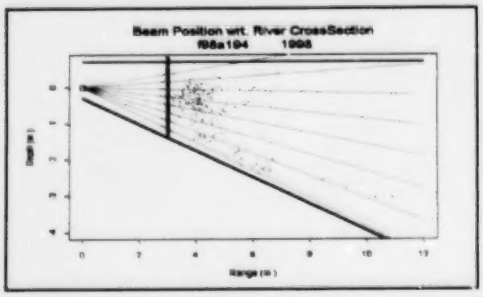
Normal



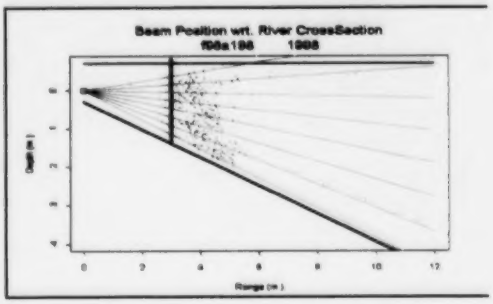
Increasing



High

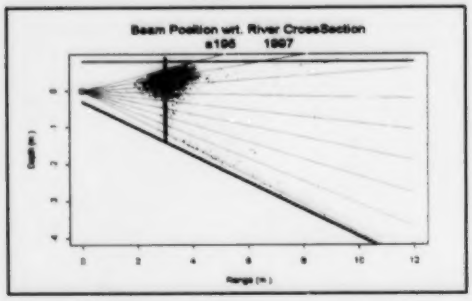


Normal



b). 1997

High



Normal

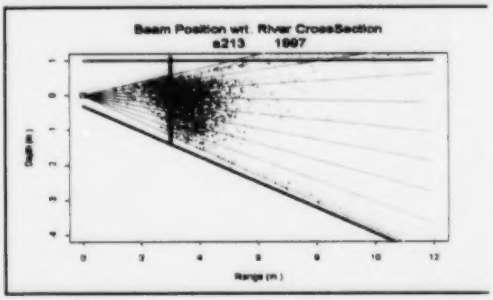


Fig. 15. Daily fan plots of fish passage detected at Qualark Creek in response to increases and decreases in river discharge in July 1998 (a: - low discharge year) and July 1997 (b: - high discharge year). Movement towards the surface when water discharge increases or away from the surface as the water discharge declines is demonstrated particularly well during 1997 when water discharge was very high. Each fan plot represents a composite of all transducer positions in the water column delineated with radiating lines. The solid vertical line represents the end of the fish deflection weir.

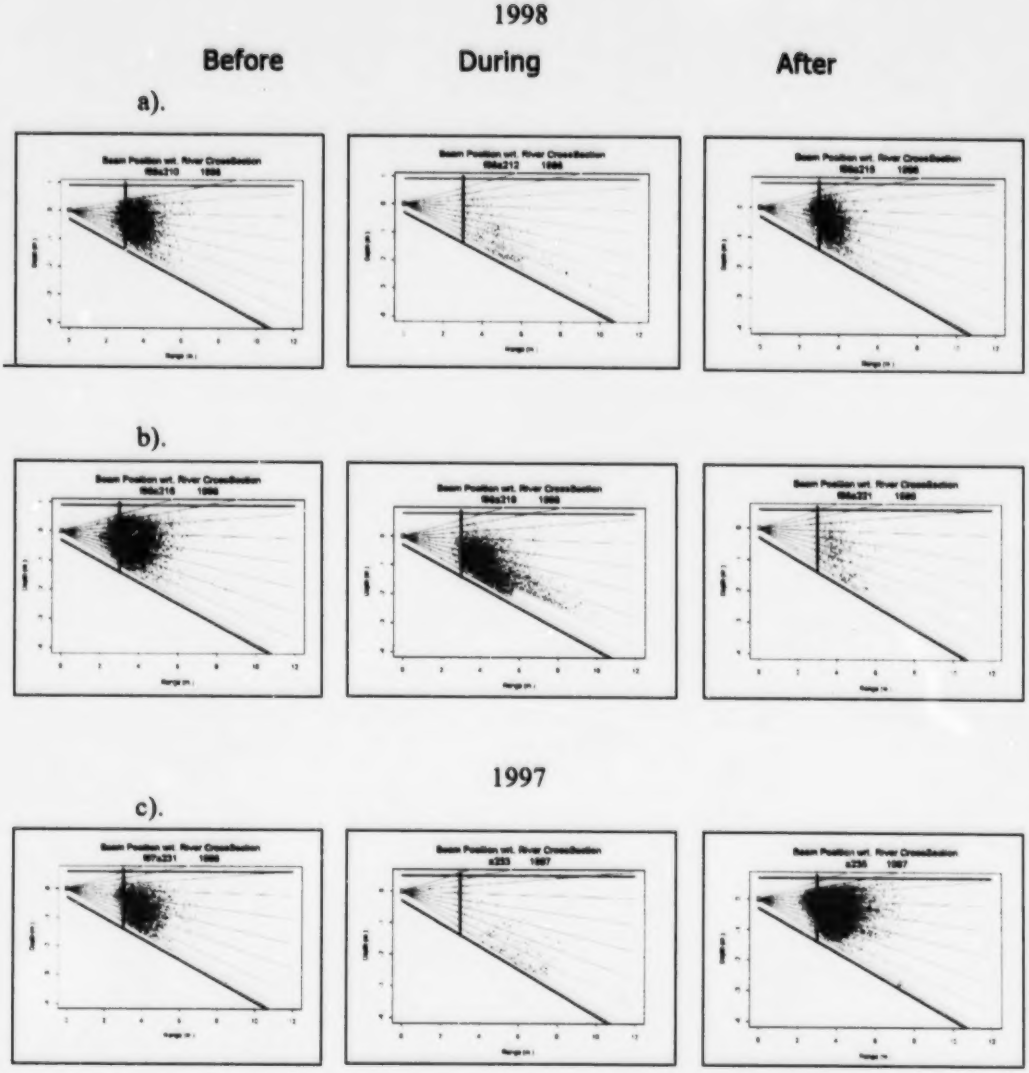


Fig. 16. Daily Fan plots of fish passage detected at Qualark Creek for three selected Julian days (a, b, and c) in 1997 and 1998. Each time sequence shows the distribution before, during and after the gillnet fishery. Each fan plot represents a composite of all transducer positions in the water column delineated with radiating lines. The solid vertical line represents the end of the fish deflection weir.

9.0 DATA COLLECTION AND PROCESSING

Data from HTI's software is stored on the DEP's hard drive in the form of five types of computer data files. These consist of:

1. *Raw* files (with the file extension *.raw) which hold records of all echoes that are above the minimum voltage threshold and pass the pulse width criteria.

2. *Echo* files (file extension *.ech) which hold records of all detected echoes that are returned from tracked targets.

3. *Fish* files (file extension *.fsh) which summarise echo files by tracked target number.

4. *Sum* files (file extension *.sum) which further summarises echo files by time.

5. *Int* files (file extension *.int) which record echo integration data.

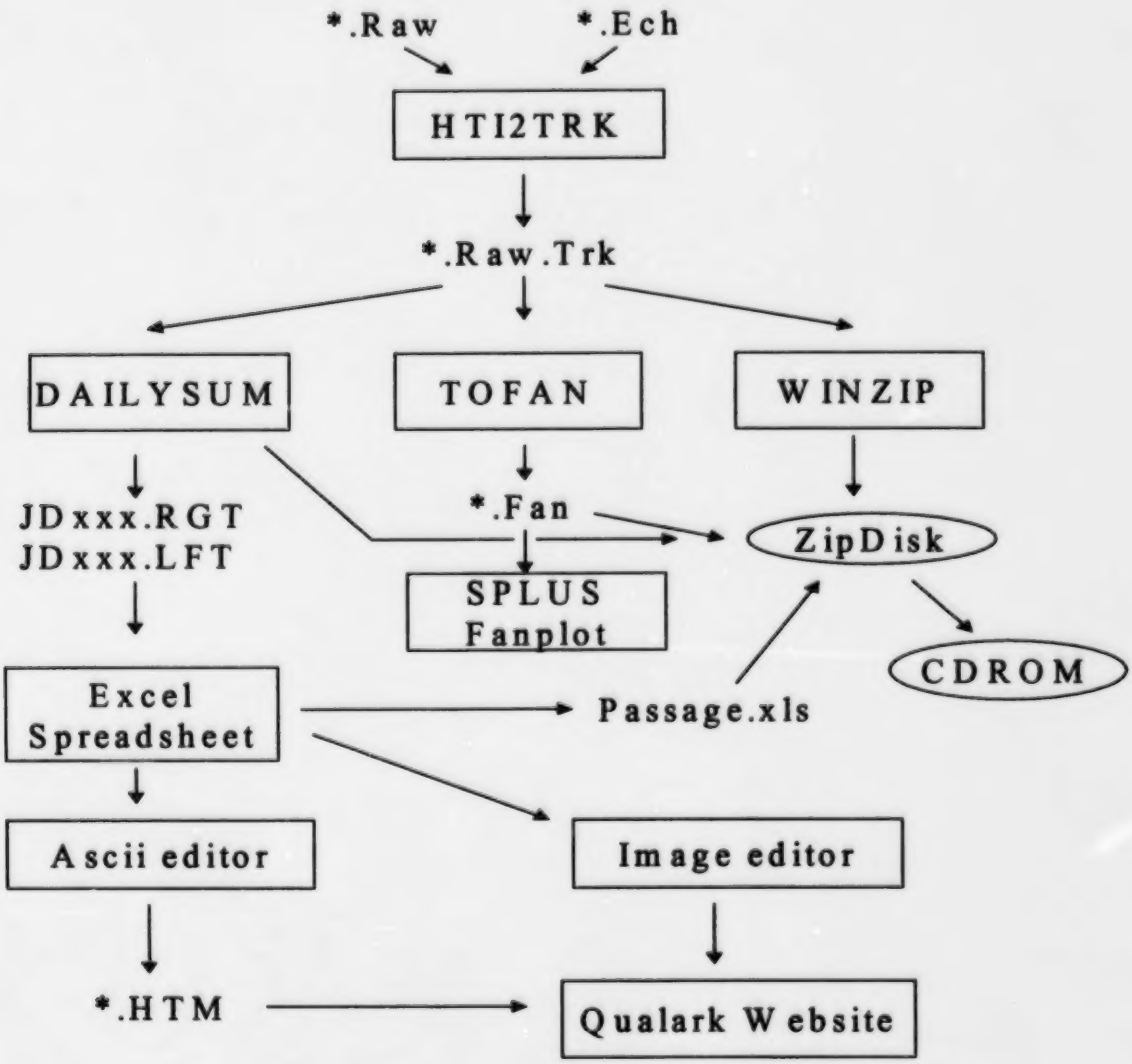


Fig. 17. Schematic of daily data processing for the passage reporting procedure done at the Qualark Creek hydroacoustic site on the Fraser River, British Columbia, Canada.

We routinely stopped collecting some of these data files as fish density increased and the size of e files increased. For example, the collection of echo integration data is not useful in estimating fish nsity in most riverine situations. Echo integration techniques rely on the assumption that the fish are ndomly distributed throughout the beam cross section. If fish passage occurs mainly on the river ttom, there is a bias in the echo integration data and therefore collecting it is unnecessary. In addition, e collection of the summary echo files is not necessary if the reporting of fish passage is done through stomised software in post processing which does its own summarising or even tracking.

The flow chart in Figure 17 shows the steps involved in processing the daily data to produce the ssage estimate for the Qualark Creek acoustic site. Only the *.RAW and *.ECH files produced by the lit-beam system are used to estimate the daily fish passage. The raw data contains the echoes that ceeded the selected voltage threshold and met the single target criteria in the case of the HTI system. e echo data is a subset of the raw data that was identified by the tracking algorithm as belonging to fish cks. The corresponding raw and echo files are fed into an editor such as that described in Xie 1999, hich converts the files into a format that we have developed for our own use. The software can then splay the raw file echogram (range vs. time) in black (Fig. 18) with the echo file data overlaid in colour ig. 19). Each different colour represents a different fish as determined by the tracking algorithm in the TI digital echoprocessor. Eight colours are used, repeating in succession.

The editor allows the acoustician to view the data in detail. Each different coloured fish trace can examined to determine if it is a valid fish trace. When a decision has been made after perusing the ulti-dimensional plots (Fig. 20) the trace can be accepted or rejected by the operator. Traces can also modified or added by the operator if tracks were incorrectly tracked or missed by the tracking gorithm. In reality, the passage of salmon at the Qualark site was often too large to allow this kind of tense review of all the tracks. This type of detailed editing ability is necessary for most acoustic xperiments and for checking the validity of fish passage data and tracker performance.

As a result of these high data volumes, the main function of the editor is to allow the operator to move the obvious noise from the tracked files to reduce the number of erroneous fish counts. Noise an originate from sources such as heavy rain, boat passage and downstream travelling debris. These pes of noise can easily be removed, giving a more accurate count of the migrating fish. Software filters an be used to remove noise, depending on the required result (Xie et al. 1997). This will be discussed in ore detail in a subsequent section. In the case where a population estimate is desired, it is not a good ea to use any filters except possibly a target strength filter to remove smaller resident fish targets. A rget strength filter must be used with caution as it may remove salmon targets if an inappropriate filter nge is used.

After the echo files have been cleaned of all the erroneous fish tracks, a file with a .Raw.Trk file xtension is produced. This file contains a combination of the raw and echo data with the data analyst's est interpretation of only the tracked fish. The data needs to be further processed to develop the results at will be presented. In the case of Qualark, this file is the input for two main routines: DAILYSUM and OFAN (Fig. 17). In addition, the results are compressed and saved onto a Zip Disc. Eventually this data saved onto a CD-ROM.

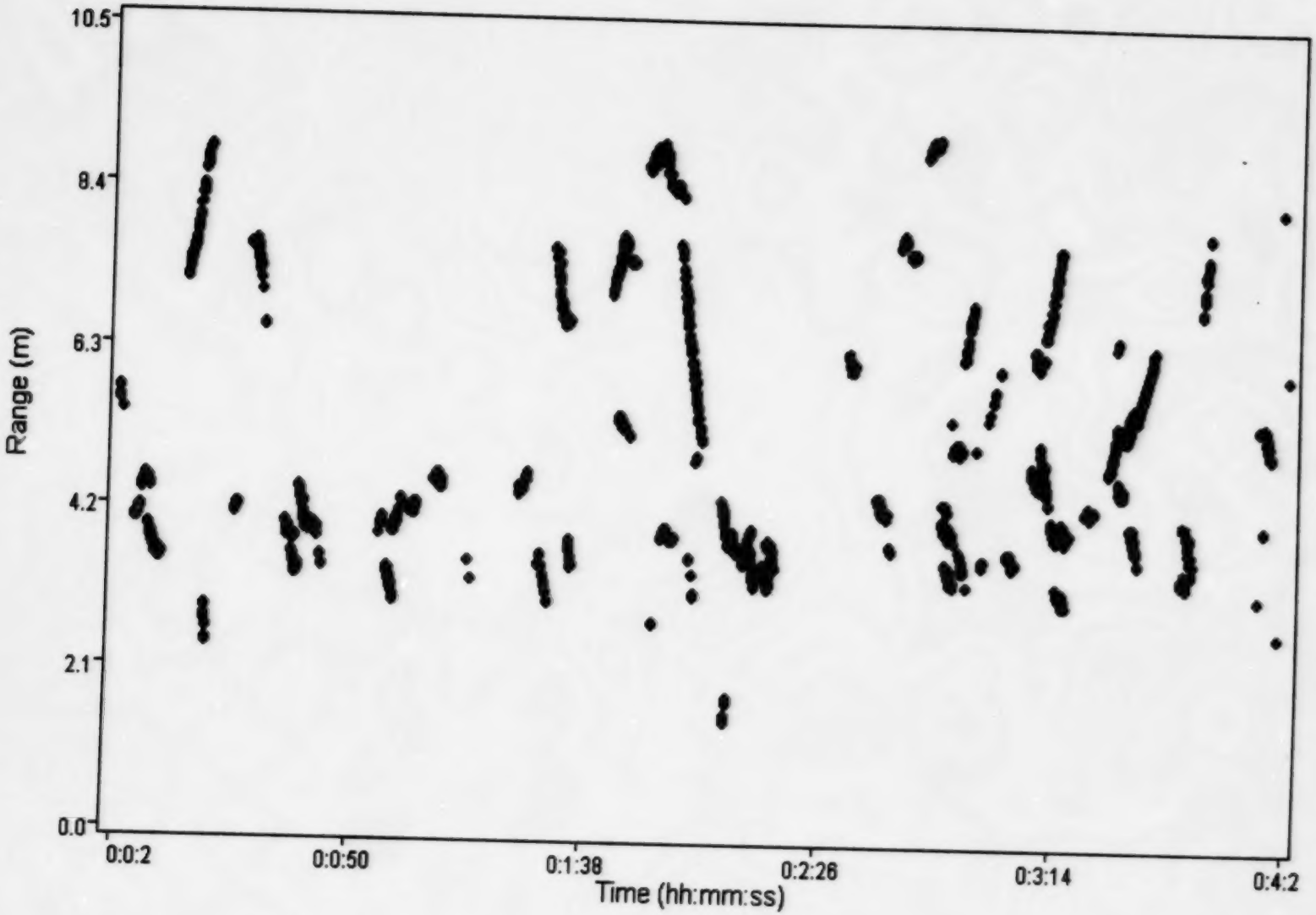


Fig. 18. Standard echogram of range vs. time for some medium fish density split-beam sonar data from Qualark Creek.

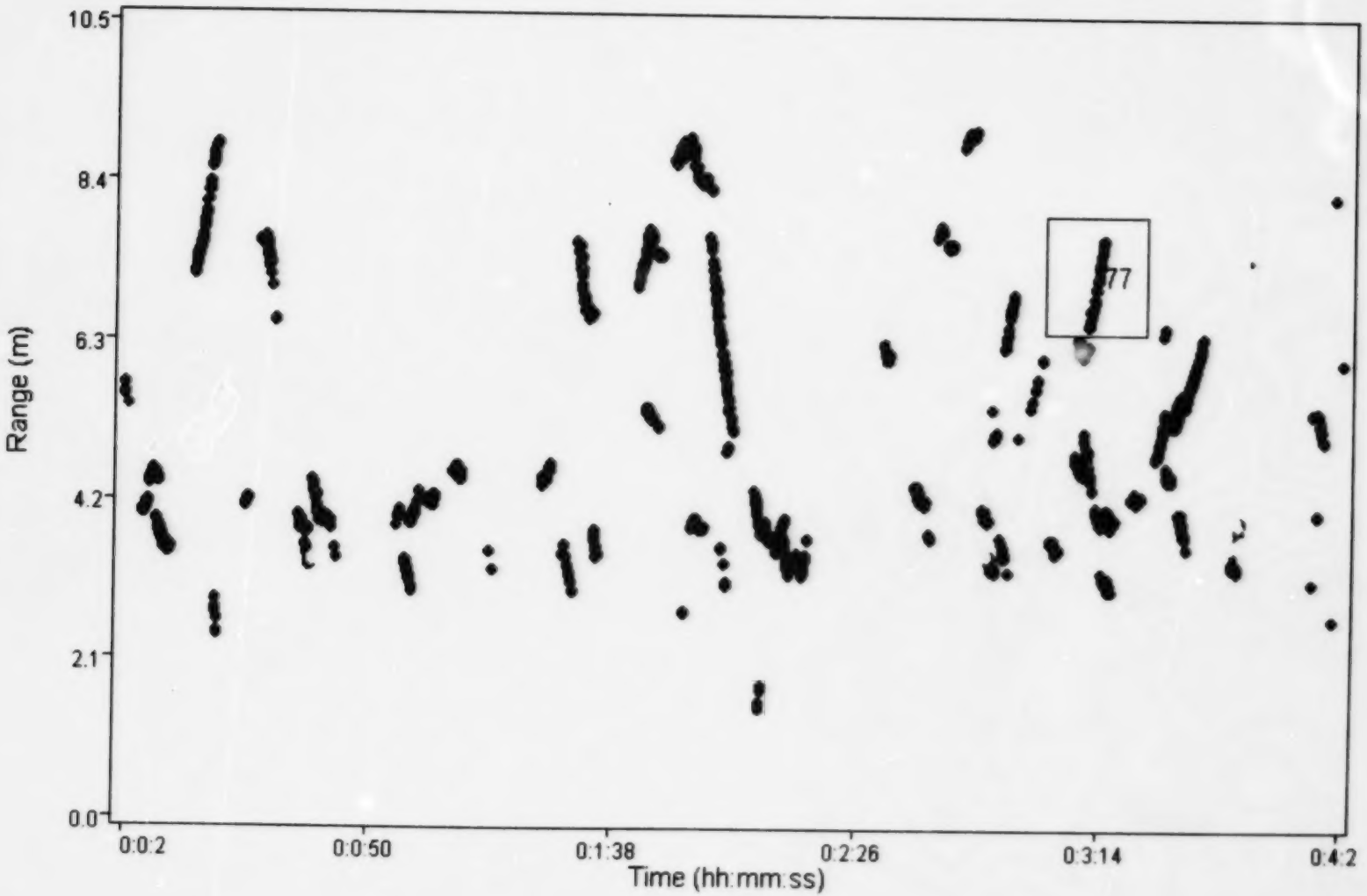


Fig. 19. Standard echogram with the tracked fish overlaid. Each colour (rotating through eight colours) represents a separate tracked fish. The track outlined with the red box and marked fish number 77 is shown in more detail in Figure 20.

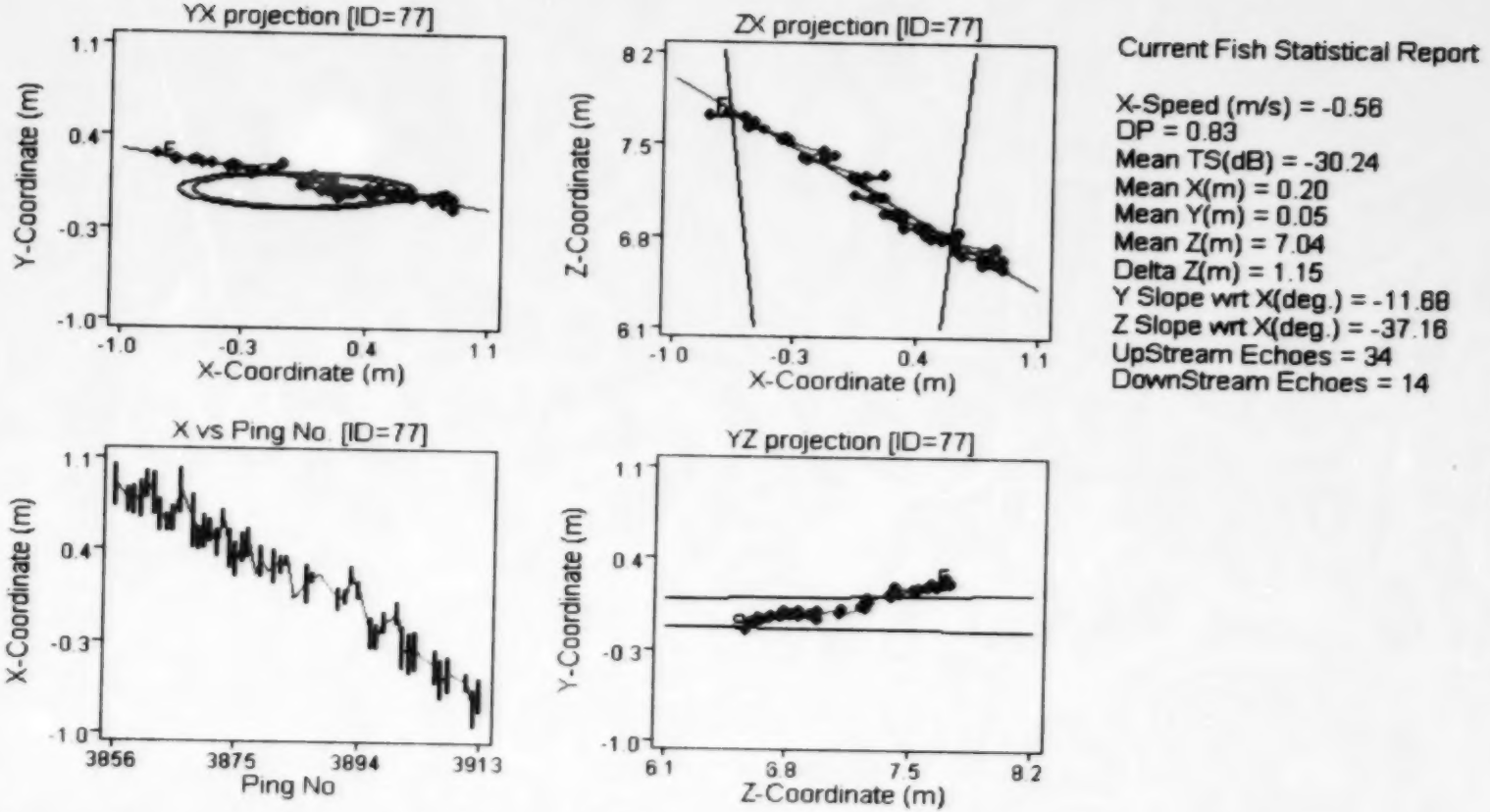


Fig. 20. The upper plots show the fish position in the YX and ZX planes. The small ellipses represent the size of the sound-beam relative to the fish trace where the fish entered the beam and where it exited. The 'S' and 'F' indicate the start and finish of the track. A least-squares fitted straight line (shown in blue) is drawn through the fish trajectory to show the straight-line approximation of the fish path. The lower left plot displays the X co-ordinate vs. the ping number for this track. The length of the green bars are proportional to the target strength of each echo. The bottom right plot displays the fish position in the YZ plane of the sound beam. Current fish statistics are displayed at the top far right including mean target strength, direction of travel, detection probability (DP) and mean speed in the X or upstream/downstream direction. These plots provide useful insight into tracker performance and fish behaviour. Please note that for the Right Bank of the river a negative X-speed means that the fish is travelling upstream.

The DAILYSUM routine was used at Qualark to produce one summary file for each bank of the river each day. The file extensions .RGT and .LFT refer to the right and left bank files respectively (by convention, when the observer is looking downstream). These data were presented in an Excel spreadsheet, which was used to produce a summary table of the results in an ASCII editor, which was then used to produce a .HTM file to present on a Web Site. The Excel spreadsheet was used to produce plots showing information such as cumulative run size, to be transferred into an image editor, which was then presented on the Web Site (Fig. 21). The Excel spreadsheet was also saved to Zip Disc and later to CD-ROM. Figure 21 is one of the figures presented on the Web Site and shows two weeks of summary data. Figures showing the daily counts for each river bank and the results of the test fishing catches were also presented. The Web Site was password protected so that we could control access to the information. Clients that were given the password would have access to all of the data for downloading for their own analyses. The Web Site is a useful concept in that it saves having to distribute the information to a large group of fisheries managers by fax or other means.

At the current time, the data editing and manipulation process summarised in Figure 17 is cumbersome and is in need of refining and simplifying. Had the Qualark programme continued, this would have been a goal to help decrease the amount of time spent on producing the daily numbers. The editing process in particular can take a great deal of time but is a necessary step in producing defensible estimates of passage.

We found it very useful to look at the daily data in a spatial way to determine if there were changes in behaviour or unusual behaviour occurring during the run. We found the most useful way to view the data was to calculate the mean position of each fish track and present this information on a side-view or 'Fan' Plot (Fig. 15). The 'Fan' term refers to the shape of the beam outlines in a multiple aim scenario where the overlying beams produce a fan shape on these plots. The acoustic beam's –3dB lines in the vertical direction are presented for each beam aim. These Fan Plots display the mean fish position in the beam in the YZ plane (as if the observer is standing in the river looking downstream at the fish travelling towards him). These plots have been very useful in showing events such as diurnal variations in migration, effects of downstream net fisheries on migration and the effects of increased flow/silt on the migration. The points on these plots can be presented as densities showing the density distributions of the salmon as they migrate upstream. Data, such as target strength, can be presented in the same way. On the lower Fraser River near Mission BC, we have noted a relationship between target strength and the distance offshore and the depth of water that the fish were travelling. The larger salmon tended to be further offshore and in deeper water. This kind of information can be very useful. If the bottom profile is accurately known and displayed, we can see if there are areas where we may not be detecting migrating salmon. These Fan Plots were done as part of our own analyses and were not presented to the fisheries managers on a daily basis. This information proved useful post-season to look at the effects of various physical changes on the salmon migration. These fan plots were saved to CD-ROM as well.

To arrive at accurate results for analyses, such as the percentage of fish travelling downstream, we need to look at only the well-tracked fish. This allows us to be certain that the results represent the fish population and do not include erroneous tracks. Two main filters were used at various times in the data analyses. These are a target strength filter as mentioned previously and an aspect ratio filter.

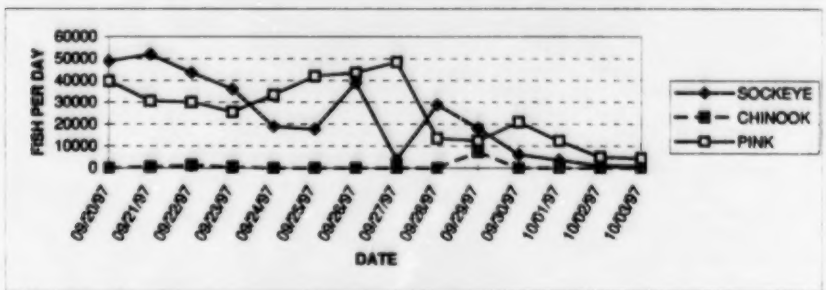
The target strength filter is used to exclude small resident fish and, less frequently a problem, large resident fish. Also the target strength filter can be used to exclude noise that can be present in large amounts during windy or rainy times or during the passage of boats. We plot the target strength distributions from cleaned data taken at times when the migrating population is predominantly adult salmon. Due to the predominance of the salmon, the range of salmon target strengths can be determined and this range can be applied as a filter range to the data gathered during the season. This type of filter acts to reduce the data cleaning time by removing most of the unwanted small fish traces and tracked noise from wind, rain and boats.

Another filter that we use is the aspect ratio filter or XY filter. This filter draws a trend line through the fish trace in three-dimensional space and then calculates the ratio of the length vs. the width of the track. It measures the spread of data points in a fish track and rejects the ones that are too randomly

spaced. A compelling fish track has good directionality and even spacing between return echoes, but it is not necessarily a straight line. After viewing many filtered files and varying the aspect ratio, we found that a ratio of 4:1, length to width, has worked well, without removing excessive data. The aspect filter has the effect of removing poor tracks such as those where the tracking algorithm has jumped between several fish traces. This jumping between traces becomes more of a problem as the fish density increases. The aspect filter subsets the data to obtain the well-tracked fish. These well-tracked data sets are then analysed in more detail to determine statistics such as the per cent downstream and the migration speed. It is necessary to obtain these statistics from the fish traces in which we have the most confidence otherwise inaccurate estimates of direction of travel and speed could occur.

SUMMARY OF QUALARK PASSAGE DATA FOR 1997

DATE	SOCKEYE	CHINOOK	PINK	TOTAL	CUMUL. PINK	CUMUL. SOCKEYE	CUMUL. CHINOOK	CUMUL. TOTAL
09/20/97	48948	0	39687	88835	306974	5221826	254872	5784433
09/21/97	51994	667	30663	83323	337637	5273819	255538	5867756
09/22/97	43561	1343	30149	75054	367786	5317381	256882	5942810
09/23/97	36048	548	25674	62270	393460	5353429	257430	6005080
09/24/97	19030	0	33441	54777	426901	5372458	257430	6059857
09/25/97	17798	0	42008	59806	468909	5390257	257430	6119663
09/26/97	38956	0	43543	82499	512452	5429213	257430	6202162
09/27/97	3886	0	48550	52436	561002	5433098	257430	6254596
09/28/97	28770	0	13626	43911	574628	5461869	257430	6298509
09/29/97	18282	7505	12511	32716	587139	5480150	264935	6331225
09/30/97	6187	0	21033	27220	608172	5486338	264935	6358445
10/01/97	3722	0	12404	16126	620576	5490060	264935	6374573
10/02/97	1134	0	5106	6240	625681	5491194	264935	6380813
10/03/97	990	0	4455	5445	630136	5492184	264935	6386258



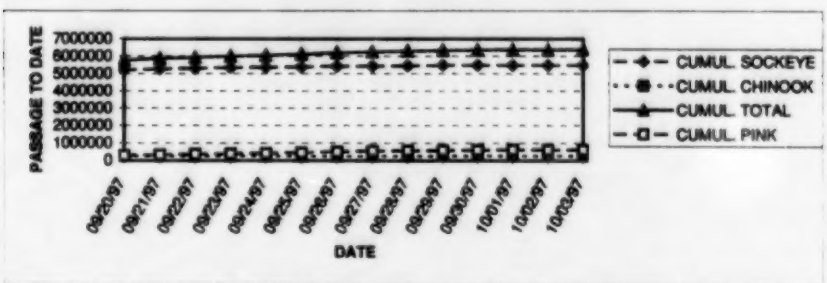


Fig. 21. Example of a summary sheet presented on the Qualark Creek Web Site showing two weeks of daily counts by species. Species composition was calculated from test fishery catches. The middle and bottom plots show daily fish numbers and cumulative fish numbers for each species.

10.0 GROUND TRUTHING THE ESTIMATION TECHNIQUE

Two key factors should be addressed if acoustic estimates are to be used for reporting daily fish passage. First, it should be verified that the hydroacoustic system adequately monitors the spatial distribution of the migrating fish in the river. We must ensure that fish passage is not occurring in areas inaccessible to the shore-based transducer. This can be accomplished by periodically surveying the areas not covered by the shore-based system with a second acoustic system. The second system we used was a single beam unit, operated in a down looking or side looking mode from a boat. With this second system we performed transects and stationary soundings and determined the presence or absence of fish in the areas not covered by the shore-based split-beam system

Second, the accuracy of the acoustic estimate should be determined by comparing it to another assessment technique that is non-acoustic. Preferably the comparison should be made on the same migrating fish. For example, we compared simultaneous acoustic and visual estimates of migrating adult salmon as they passed through a delineated sampling area. We video taped, visually counted, and acoustically detected and tracked the migrating salmon. This work is described in Enzenhofer et al. (1998) and was done to determine the bias and variance of the estimates produced by the acoustic system at Qualark. This was achieved by simulating the conditions present at the Qualark Creek site. The simulated conditions included migrating fish being forced off shore around a weir to pass through the acoustic beam at relatively close range.

Another method to test for presence/absence is a drift gillnet sampling program. We operated a drift gillnet sampling programme that paid for itself with the catch of salmon and showed us the presence/absence of fish in areas of the river not covered by the split-beam system. In addition, the test fishery provided a rough indication of species composition and allowed an opportunity to gather biological and genetic samples. The test fishery also provided a test of acoustic function in that there should be a good relationship between acoustic estimates and gillnet CPUE.

Another study by Mulligan and Kaiser (1986) describes a comparison of an acoustic population estimate of salmon in a lake with a weir count. A similar study could be done using a fixed-location split-beam system to estimate fish passage and compare the results to fish numbers counted through a weir placed downstream from the acoustic system. This is assuming that the physical characteristics of the river are suitable for this type of testing. Often this is not the case.

A more difficult task would be to compare an acoustic to non-acoustic estimate for fish passing a fixed-location site at longer range. Being able to visually count fish moving over a large area becomes increasingly difficult. The use of known numbers of targets, returning the same signal strength as adult salmon that are passed through the acoustic beam at longer ranges could be attempted. These targets could be deployed in a multiple array suspended from a harness that allows the target path, depth and target speed to be controlled.

These types of ground truthing experiments are needed to produce confidence in the acoustic estimates. Often these experiments are difficult to develop and carry out, but they are well worth the effort to obtain a measure of this enumeration method's accuracy and precision.

11.0 CONCLUSION

We believe that the equipment and methods presented in this report can be applied to most riverine acoustic enumeration facilities. We also believe that for accurate and defensible acoustic enumeration of migrating fish stocks, these techniques are important, if not essential. Several years of research and development have gone into the Qualark Creek site and we have been able to show that our estimates of salmon passage have greatly improved due to the changes we have made. We anticipate that in presenting our developments we can save others time in starting new riverine facilities.

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